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NAVIGATION WORKS EXECUTED IN FRANCE FROM 1876 TO 1891.

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The work presented in the following memoir is a collective work—that of the engineers of the Corps des Ponts et Chaussées, who are the engineers of the French government. It has been prepared with the concurrence of the chiefs of the principal departments of river and maritime navigation in France. The writer has had besides, as colaborers—for the technical description of the interior navigation works, M. Holtz, Inspector-General, Professor of Internal Naviga-

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tion at l'École des Ponts et Chaussées ; for the technical description of the maritime works, M. Quinette de Rochemont, Inspector-General, Professor of Ports at the same school ; for the financial and statistical part, M. Beaurin-Gressier, Chief of the Division of Navigation in the Department of Public Works.

The subject comprises two distinct parts—first, interior navigation works ; second, maritime navigation works.

There has been no effort made to give a detailed description of all of the navigable routes of France, and of the numerous maritime ports which serve for its traffic by sea ; nor to retrace the history of the composition of the system and of the installation of the ports. This description and this history have already been presented in numerous and voluminous works, some of which will appear at the exposition connected with the International Congress of Civil Engineering.*

It appears to the writer that it would be interesting to bring out the principal improvements of a technical or economic order executed in recent years upon our navigable routes and ports ; to give at least a rapid glance at all of them ; to indicate the nature and the cost of these improvements, their influence upon the development of traffic, the new facilities of all sorts assured to circulation, and the reductions obtained in the cost of transportation.

This programme adopted, it is only necessary to fix the beginning of the period to be considered, which has been taken at the year 1876. This year corresponds in France to a marked return of interest in navigation. It is from this year that a certain number of laws date which authorize the execution of important works, and that interest increased in the following years. A vast programme of improvements of rivers, canals and ports was brought forward in 1878. This resulted in 1879 in two important bills (July 29th, for maritime ports; August 5th, for navigable routes), which divided water-ways and ports into several classes, and determined for each the technical conditions which should be followed.

The choice of the year 1876 for the starting point permits the consideration of a period of 16 years which terminates at the begin-

* Guide officiel de la Navigation intérieure. 1892. Baudrey et Cie., éditeurs.

Statistique de la Navigation intérieure. Relevé du tonnage. 1892. Impie. Natale.

Statistique de la Navigation intérieure. Dépenses d'établissement et d'entretien. Documents historiques et statistiques. 1892. Impie. Natale.

Ports maritimes de la France. Texte et Atlas. Impie. Natale.

ning of the year 1892. The length of this period is sufficient to include the necessary delays in the preparation and execution of projects, and one can at least ascertain the first results. The enterprises begun in this period are not all completed. The original plans have, in fact, been modified by cutting down or adding to. But a considerable and very important part of the work in progress in 1876, in 1879, and in the following years is to-day completed, and has commenced to bear fruit. One can thus study the results of the effort, and give an account of the influence of the works undertaken upon the economic conditions of the regions traversed.

INTERIOR NAVIGATION WORKS.

SECTION I.—GENERAL STATEMENT.

For the proper understanding of the explanations which are to follow, let us at first recall how the network formed of the principal lines is made up, at least all that part of it upon which the work of improvement for the last dozen years has been expended.

The lines upon which the traffic is the most important are concentrated in the regions of the north, of the center, and of the east. The first place belongs by right to the Seine, which flows through Paris, the capital of the country. This river constitutes, of itself, a great line of navigation. Down stream it connects Paris with the sea, at the ports of Rouen and of Havre. Up stream, it forms as far as Montereau the trunk of two great lines leading toward the basin of the Rhône and the Saône. One of these lines, passing through Burgundy, follows the Yonne (85 km.) as far as La Roche, then the canal of Burgundy (242 km.), and joins the Saône at St. Jean de Losne. The other, passing through Bourbonnais, follows the canals of the Loing (50 km.) and of Briare (59 km.), the canal along the Loire (193 km.), the canal of the center (116 km.), and joins the Saône at Châlons-sur-Saône.

Below Paris, the Seine connects with the system of navigable waterways of the region of the north. The principal branch of this system includes 283 km., formed of the Oise canalized, the canal by the side of the Oise, the canal of St. Quentin, of a part of the Escaut and of a part of the canal from Mons to Condé. It is prolonged by two branches, one of which, very important, extends toward Charleroi and is formed of the Sambre and of the canal from the Sambre to the Oise (125 km.), while the other extends towards Tournay (15 km.).

From the principal line connecting Paris with Belgium there branch: first, the canal of the Somme (156 km.), starting from St. Simon, on the canal of St. Quentin, to connect with the port of St. Valéry, in Manche; then the special system of the departments of the North and of Pas-de-Calais, the numerous branches of which serve the industrial centers of this region, while their principal extremities extend to the Belgian frontier, and to the ports of Dunkirk and Calais.

Above Paris, the Seine is connected by the Marne with a line leading to the eastern frontier, comprising the Marne (179 km.), the canal along the Marne (63 km.), and the canal from the Marne to the Rhine (210 km.).

In the east, a great line 432 km. long extends from the north to the south, under the name of Canal of the East. It starts from Givet (Belgian frontier) and joins the Saône at Corre. From this last line one can follow the Saône, which receives the two lines from Paris to Lyons by Burgundy and Bourbonnais, to its junction at Lyons, a distance of 374 km.; then the Rhône from Lyons to the Mediterranean, 334 km. In order to complete the description of the principal features of this part of the French system, there should be mentioned the water-ways joining the lines from Paris to the Belgian frontier, from Paris to the German frontier, and the Canal of the East, These are: the canal of Ardennes (88 km.), the canal along the Aisne (51 km.), that from the Aisne to the Marne (58 km.), and the canal from the Oise to the Aisne (48 km.); finally, as new routes, still incomplete, the canal from the Marne to the Saône, which will be 153 km., and the canal from the Doubs to the Saône, which will be 82 km.

A certain number of secondary lines of the east and of the center are omitted from this enumeration. The rest of the system comprises, in the south, the lines connecting the Mediterranean with the ocean; in the southwest, the water-ways of the basins of the Garonne, of the Dordogne, and of the Adour; in the west, the water-ways of the basins of the Charente and of the Sèvre; in the northwest, the canals of Brittany, and a certain number of water-ways in secondary basins of little importance. Upon these last lines, and except the work executed at the mouths of our large rivers, there has been, from 1876 to 1892, no work of transformation of sufficient importance to receive a place in the present study. The actual length of the water-ways in habitual use in the French system is a total of 12 327 km., viz.: rivers, 7 522

km.; canals, 4 805 km. Nearly all of these routes are administered by the State; those operated privately include a length of only 858 km.

After the few years of rest which followed the war of 1870, France undertook the work of developing its routes of transportation. During the 20 years preceding, the railroads had been in almost exclusive favor, to the detriment of the water-ways. Since 1871, the services which rivers and canals would be able to render have been better understood, and the work of completing and perfecting the system of water-ways has been resolutely undertaken.

The first works which were organized were those for the establishment of the Canal of the East, and for the canalization of the Saône, prescribed by two laws of March 24th, 1874; a considerable work designed to re-establish the continuity of the lines intercepted by the new frontier, and which was only completed in 1887. The first of these cost over 100 000 000 francs. Construction work was soon after begun upon the Saône on a dam at Mulatière in the Lyons slack-water level (Decree of March 12th, 1875), and in the north, the improvement of the routes in the valley of the Aa was begun, in order to secure a depth of 2 m. Studies were pursued at the same time at other points, which resulted, in 1876, in the presentation to Parliament of several important projects. Let us mention the principal ones, in the order of the dates of the votes on the laws which resulted:

Creation of a depth of 3.20 m. upon the Seine, between Paris and Rouen (law of April 6th, 1878);

General improvement of the Rhône, between Lyons and the sea (law of May 13th, 1878);

Establishment at Paris of landing places (*bas ports*) and quays (law of June 7th, 1878);

Creation of depth of 2 m. upon the Seine, from Paris to Montereau (law of June 13th, 1878);

Creation of a depth of 2 m. upon the Yonne, from Montereau to La Roche (law of June 13th, 1878);

Improvement of the canal of Burgrndy, having for its object an increase of the depth of the water, the lengthening of the locks, the raising of the bridges, increasing the water supply, etc. (law of June 13th, 1878).

Having arrived at this point of the work of transformation, the discerning public believed that before going farther it would be profit-

able to so modify the programme of the work to be done as to include the completion of the system, and, above all, to give to the different lines constructed heterogeneously during the preceding period, a unity of design which should materially increase the facilities of transportation. The programme thus modified was sanctioned by the law of August 5th, 1879. It had for its object the improvement, unification and completion of the system. It determined, as a whole, the classification of navigable ways, the régime to which they should be submitted, as well as the technical conditions of establishment. It divided them into two classes, principal lines and secondary lines. The first were those which served the general interests of the country. It was stipulated that they should be administered exclusively by the State. The others, of less importance, could be conceded for a limited time, with or without subsidies, to public societies, to associations, or to individuals.

The law fixed the dimensions of all the principal lines as follows: Depth of water, 2 m.; width of locks, 5.20 m.; length of locks measured between the chord of the lift-wall and the hollow quoins of the tail gates, 38.50 m.; clear height under bridges, 3.70 m. These dimensions are necessary over the entire territory, in order to insure the circulation of boats of 300 tons, of the type most common in France, that of the Flemish canal-boat. But these are only minima, and the law has placed no obstacle in the way of the adoption of larger dimensions, especially upon rivers and streams where boats can be used particularly appropriate to river navigation.

As to secondary lines, they have not been subjected to these rules; but in practice, it is sought to have them conform to them as far as possible, though it is not imperative.

The law contained the nomenclature of navigable ways, which determined the character of principal lines, and established the principle upon which the few concessions of these lines still existing should be extinguished. Such is the general character of the law of August 5th, 1879, which has given a strong impulse to interior navigation works, by directing them toward a definite end.

From 1876 to 1892 the labor of completion and of unification of the system was definitely carried out on 688 km. of new water-ways and 3 969 km. of improved water-ways, or omitting the water-ways upon which the works have not yet been completed, and from the estab-

lishment or improvement of which commerce has not yet been benefited, there remains 625 km. of new water-ways and 3 326 km. of improved water-ways.

Following the order of the preceding observations, we will now review the principal results which have been developed, taking up first the technical details and then the cost and traffic.

Section II.—Technical Considerations.

Chapter 1.—Construction of New Water-Ways.

The new works opened or undertaken since 1876 are the following:

	Kilometers.
Canal of the East, and branches	432
Canal of the Upper Marne, and Vassy branch	100
Canal from the Oise to the Aisne	48
Canal from Lens to the Deule	8
Tourcoing Branch	2
Canal from the Marne to the Saône (under construction)	153
Canal from the Doubs to the Upper Saône (under construction)	82

The works of the Canal of the East and those of the Canal of the Upper Marne were commenced at the beginning of the period considered in this study. The works of construction of the other canals were only begun after the vote of the programme of 1879. All the works comprised in the preceding list, with the exception of the canal from the Marne to the Saône, and of the canal from the Doubs to the Saône, are open to navigation.

Canal of the East.—The great navigable route thus designated had been conceived previous to the programme of 1878, and was decided upon after the war of 1870, with its principal object the re-establishment upon French territory of the communications intercepted by the new frontier. It traverses the east of France in a direction from north to south from Givet, where it forms the prolongation of the Belgian Meuse to Corre, and there joins the canalized Saône. It thus constitutes a water-way as direct as possible between the basin of the Meuse and that of the Rhone, between the North Sea and the Mediterranean.

It is made up of two principal branches, called the Northern branch and the Southern branch. The first starts at Givet, near the Belgian frontier, and ascends the valley of the Meuse, sometimes in the river,

sometimes as a lateral canal, as far as the canal from the Marne to the Rhine; its length is 272 km. Thence for a length of 22 km. it coincides with the canal from the Marne to the Rhine, previously constructed, and passes by the tunnel of Toug from the valley of the Meuse into that of the Moselle.

At Toul the southern branch begins and first follows the canalized Moselle; it then extends by canal to the divide and crosses the summit of the Vosges at an altitude of 361 m. above the level of the sea. Its length is 147 km. Two branches, one of 10, the other of 3, km. in length, extend to the cities of Nancy and of Epinal left to one side by the main line. Its total length, including the branches, is then 432 km.

In the parts in the river, the movable dams are trestle and needle dams of the Poirée system. Here are 175 locks having the regulation dimensions fixed by the law of 1879. Upon the north branch the water supply is naturally secured by a feeder direct from the Meuse. In the part from the Marne to the Rhine the supply is secured by powerful hydraulic engines, which are operated by the falls of the dams of the canalized Moselle above Toul. The power thus utilized varies according to the stage of the river, from 400 to 600 H. P., and the height of lift is 40 m. The water is forced up in cast conduits following the line of greatest declivity of the slope. These open into channels which have a total length of 13 km., and include two large cast-iron siphons and a tunnel. On account of the permeability of the soil, they are lined with concrete for a part of the distance.

A part of this water is again taken at Vacon and lifted anew by a steam pump to a height of 40 m., for the special supply of the summit level of the canal from the Marne to the Rhine. It reaches this level by a channel 8 km. in length, 7 km. of which are in an open masonry channel, and 900 m. in a siphon of cast-iron pipe. The volume of water raised yearly by the first group of engines is, on an average, 5 000 000 cu. m., and of the second, 3 000 000 cu. m.

The summit level of the south branch and the two levels next the summit, one each side, take their water from a reservoir constructed at Bouzey, which has a capacity of 5 000 000 cu. m., and is filled by the rainfall on its drainage area and by a feeder 42 km. long from the Moselle at Remiremont.

As to the Nancy branch, which constitutes by itself a small canal at the junction of the Moselle and Meurthe, it is supplied exclusively by

means of hydraulic engines, which are worked by the combined fall of two locks, and which pump the water of the Moselle to the summit level. The same engines supply the city of Nancy.

The different machines constructed for the water supply of the Canal of the East and of the canal from the Marne to the Rhine have worked for several years with perfect regularity, and they must be regarded as the newest and most original features, while at the same time they have been the most successful of any on this entire work.

The total cost of the canal reached in round numbers 100 000 000 francs. The labor lasted eight years, from 1874 to 1882. This considerable work was designed and carried to its completion by the late M. l'Inspecteur-Général des Ponts et Chaussées, Frécot, whose name remains inseparable from that of the Canal of the East.

Canal from the Oise to the Aisne.—This canal was included in the programme of 1879. It branches from the canal along the Oise near Chauny, ascends the valley of the Ailette, an affluent of the Oise, crosses the ridge separating the basins of the Oise and Aisne by the aid of a tunnel 2 365 m. long, and joins the canal along the Aisne near the lock of Bourg, by way of the valley of Braye-en-Laomois. Its length is 48 km. Its object is to improve the water communications between the north and the east of France; it effects a saving in distance of 58 km. over the old routes, and does away with 60 km. of precarious river navigation, and thus assures economy and regularity in transportation in one of the directions of most importance.

There are 13 locks. The supply of the summit level, and of its two levels down to the first feeders, as upon the Canal of the East, is by means of powerful hydraulic engines. These are turbines, which pump the water to a height of 16 m., worked by water from a feeder established in the Aisne, and which embody all the improvements that have been brought out during the last 25 years in this sort of construction. This method of supply is supplemented by a small reservoir of a capacity of 1 000 000 cu. m., designed to help in filling the canal after it has been emptied, or to aid in the different contingencies which may arise during operation.

The tunnel of Braye, by which the canal crosses the ridge, presented exceptional difficulties in its execution. It is driven entirely through the lower strata of the *Suessonien*, but, at the entrance, on the slope of the Oise, the beds of clay form a pocket with the bottom

about 300 m. from the entrance. At this point, the accumulated water brought with it fine sand which covered the clay and rendered all work in the open air impossible. In order to overcome this, it was necessary to make use of compressed air; but then other difficulties arose. The compressed air induced the combustion of the lignite which was mixed with the clay and caused grave accidents, one of which cost the lives of 17 workmen. Thanks to the opening of a vertical shaft, and to energetic means of ventilation, they were able to continue and complete the work in the midst of the double danger of fire and flood. The expense per linear meter in the part constructed in compressed air has reached 6 720 francs. The canal was opened to navigation in 1890, and its tonnage rose in the very first year to 1 100 000 tons.* Its total cost of construction was, in round numbers, 35 000 000 francs.

Canal of the Upper Marne and from the Marne to the Saône.—Under different names, these two canals constitute only a single navigable route, designed to put the industrial regions of the north in communication with the basin of the Rhône by a more direct line than that which connects them to-day. The first part, 77 km. long, ascends the valley of the Marne alongside of the river from Vitry-le-François to Rouvroy. It was under construction from 1865 to 1879, and was put in complete operation in 1880. It is supplied by feeders from the Marne, and contains 33 locks. The cost exceeded 17 000 000 francs.

The second part, which has received the name of canal from the Marne to the Saône, forms a prolongation of the preceding. It starts at Rouvroy, the extremity of the canal of the Upper Marne, and continues to ascend the valley of the Marne as far as Langres; it then crosses, near this city, the ridge separating the basins of the Marne and Saône by a tunnel 4 825 m. long, and descends by the valley of the Vingeanne to its confluence with the Saône near Pontailler. Its total length is 153 km. The works, undertaken in 1879, are fully under way; the summit level, including the tunnel, is finished, but its adjacent levels still present two gaps of a total length of 55 km.

This canal comprises numerous structures, among which may be mentioned several aqueducts across the Marne, and the great tunnel through the ridge, one of the most important which has been constructed for the passage of a navigable water-way. The grade is overcome upon the slope towards the Marne by 40 locks; and was to have

* The ton used throughout this paper is the French *tonne* of 1 000 kg., or 2 204 lbs.—*Trans.*

been overcome upon that towards the Saône by 44 locks and 2 elevators; but locks with high lifts in construction were substituted for these latter.

The supply is assured, in the lower portion of the canal, by feeders from the Marne and the Vingeanne, and in the upper part by four reservoirs, capable of impounding 45 000 000 cu. m. Two of these reservoirs, that of Liez and that of Mouche, have been constructed. The first has an available capacity of 15 400 000 cu. m. Its embankment of earth has a maximum height of 14.4 m., and has been constructed according to the usual French method, by means of a homogeneous puddle core, formed of a mixture of sand and clay, and thoroughly compressed by a steam-roller.

The second reservoir has a capacity of only 8 700 000 cu. m.; but the height of the walls reaches 22.50 m. above the bottom sluice gates, and the dam is of masonry. It has been constructed according to the profile approved in France by the examples of the large reservoirs of Furens, of Ternay, of Ban, of Chartrain, that is to say, starting with vertical faces, and changing to a light batter on the up-stream side, and a strongly inclined curved face on the down-stream side, so as to offer the necessary resistance at the base, and in each of the horizontal or oblique sections. The thickness was determined by the methods of MM. Delocre and Bouvier, with the modifications which have been added since by M. Guillemain. The top of the wall carries a road supported by arches projecting on the lower face; this happy arrangement gives it a decidedly architectural appearance.

The total cost of the works on the canal from the Marne to the Saône is estimated at 80 000 000 francs, of which about 55 000 000 francs have already been expended.

Canal from St. Dizier to Vassy.—This canal connects with that of the Upper Marne, but is only a branch designed to serve the smelting establishments of the valley of the Blaise. Its length is 23 km.; it was constructed between 1880 and 1883, and is to-day in full operation. It is supplied by the waters of the Blaise and by a small reservoir of 2 000 000 cu. m. capacity. Classed with the secondary canals, it has been let to a company which carries it on by means of a toll. The expense of 5 200 000 francs has been met, two-thirds by the State and one-third by the company to which it was conceded.

Canal from Montbeliard to the Upper Saône.—The last-built navigable

water-way to be mentioned is the canal from Montbeliard to the upper Saône, which will complete, with the Canal of the east, the restoration upon French soil of the communication intercepted by the new frontier, and serve, besides, the coal mines of Ronchamps.

Like all the preceding, with the exception of the Vassy canal, it is classed with the principal lines which the State constructed on the strength of its budget, and which it should itself administer. The works are much less advanced and have been carried on exclusively up to date upon the summit level, by means of which this canal will cross the ridge separating the basins of the Doubs and of the Saône, and upon the large supply reservoir with a masonry dam, situated in the neighborhood of this level. Under this head the expenses have already risen to 10 000 000 francs.

Chapter 2.—Improvement of Existing Water-Ways.

The preceding description shows the importance of the works in progress since 1868, which are required to fill up the gaps that the system of navigable ways in France still presents. All the lines recently constructed correspond, moreover, in their technical requirements, to the regulations prescribed by the law of August 5th, 1879. But by far the greatest part of the task accomplished since that date has consisted in the improvement of existing routes. Their depths have been increased to a minimum of 2 m., the locks have been reconstructed, placing the width at 5.20 m. and the length at 38.50 m., and the sources of supply have been increased to satisfy the new requirements. This work was done while the ways were in full operation, at the same time reducing as much as possible the delays and restrictions to navigation caused by the work in progress.

This work is to-day nearly completed, at least upon the principal lines. It has brought up difficult problems, exercised the sagacity of the engineers, and imposed expenses greater than those which have been contracted in the same period in the construction of new lines. The length of navigable ways on which a depth of 2 m. exists at all times has reached 4 787 km. The rivers and canals, of which the locks have at least the regulation dimensions, represent a total length of 3 956 km. Finally, the improved routes which fulfill the two conditions necessary for giving passage at all times to boats 38.50 m. long and drawing 1.80 m., include a length of 4 014 km.

The following table gives the situation in 1878 and at the present time :

Total length of navigable water-ways having a minimum depth of 2 m., and locks of 38.50 x 5.20 m.

	RIVERS.	CANALS.	TOTAL.
	Kilometers.	Kilometers.	Kilometers.
Situation in 1878	996	463	1 459
Present situation	1 934	2 080	4 014
Differences	938	1 617	2 555

Important results have followed from these great improvements. The principal lines now constitute, in their entirety, a homogeneous system upon which the same boat can go from one extremity to the other without breaking cargo, whatever may be the nature of the route over which it passes, the altitude which it reaches in passing from one basin to another, or the climatic conditions of the regions.

Undoubtedly ice, river floods, and inclement weather will never permit of attaining the same regularity as upon railroads. Nevertheless we approach it as closely as possible; we give to the navigable water-way a uniformity which was lacking to it, thus facilitating transportation by water to great distances, and allowing the system to develop under the most favorable and economical conditions.

STREAMS AND RIVERS.

The Seine, from Paris to Rouen.—Upon most of the canalized rivers it has been possible to raise existing dams, often, indeed, to replace them by other structures. Those of the Seine, between Paris and Rouen, should be placed in the first rank of such works.

In view of the exceptional importance of this route a depth of 2 m. has not been considered sufficient; and it has been extended to 3.20 m., in order to assure the passage of boats loaded to a draft of 3 m. This work is now completed; the expense, including that of the Paris slack-water level, has reached 61 000 000 francs.

The natural fall of 25.50 m. in the Seine, between the locks of Port-à-l'Anglais, above Paris, and the lowest level of the open sea, below the lock of Martot, near Rouen, a distance of 225 km., has been over-

come by nine dams with locks. There are at least two locks at each dam; the large one has a width at the entrance and exit of 11.80 m., with an available length of at least 151.80 m.; and is designed especially for convoys, which it can receive unbroken, with their towboats; the second, of smaller dimensions, is designed for single boats. The Seine, between Paris and the sea, thus allows the passage of special seagoing vessels having the smokestacks and masts so arranged that they can be lowered for passing under bridges. It is, moreover, frequented by river barges having a net tonnage as high as 1 000 tons, independently of shallops of 300 tons which navigate it in full security.

The locks of Bougival, which serve a double traffic, that from Paris to Rouen by the Seine and to Belgium by the Oise, pass more than 3 000 000 tons per year. They are provided with hydraulic apparatus, which is operated by the fall at the dam of Marly, and by the aid of which all the movements are made by hydraulic pressure.

The dams contain one or more navigable passages, and higher passages or weirs; their modes of construction and closing vary with the locality. Three of them are old trestle and needle dams; the other six can be assigned to two principal types, that of Suresnes and that of Poses.

The dam of Suresnes, built by M. Boulé, Inspector-General, immediately below Paris, at the head of the islands of Puteaux and of La Folie, is composed of three distinct passages, having a total length of 197 m. The normal fall is 3.27 m. What characterizes this dam is the employment of trestles copied from the Poirée system, but extended to a height which had never been attained in that system; their total height varies from 4.14 to 6 m. They are operated by a chain moved by means of a fixed winch placed upon the abutment. Two methods have been adopted for closing which are used alternately, the sliding gates of M. Boulé and the curtains of M. Caméré.

The Boulé gates are made of planks; these rest vertically one above the other, and are supported laterally on two adjoining trestles. The Caméré curtains are composed of a series of horizontal timbers joined by articulations which form hinges. They are supported by two adjacent trestles and, by means of a chain, are held and rolled up like an awning when one wishes to let the water take its natural course.

Gates, or curtains, replace the needles of the primitive Poirée sys-

tem; the operation is by means of a windlass which rolls along the service bridge. They thus obtain solidity, freedom from leakage and facility of operation, while the height of water in the Paris slack-water level can be regulated with great precision. This great dam has worked for several years with perfect regularity, and the expense has been about 10 370 francs per running meter.

At Poses the fall exceeds that of Suresnes; it is 4.14 m., which is greater than had been overcome by means of a movable dam. It is dangerous to depend upon parts constantly submerged to so great a depth. The work was designed by M. Caméré, Engineer-in-Chief, on a new system, which was originated by the late M. Tavernier for the Rhône; but the first application of it was made upon the Seine.

The dam of Poses has a total length of 235 m., divided into seven parts of greater or less depth, each having a length of 30 m. The piers which separate them support a fixed bridge placed at a height sufficient, when the dam is open, for the free passage of the largest floods, as well as the boats.

At the lower part of this bridge, on the down-stream side, long wrought-iron beams are hinged, which hang down to the sill and rest against a projection on it. These beams thus supported at both ends replace the trestles and receive the articulated curtains which close the passage. For the free passage of water the curtains are rolled up; then the beams under the bridge are raised by means of a windlass, and the river is absolutely free, while the working parts fixed to the service bridge above, which is more than 4 m. above the highest water, can be easily maintained and repaired.

Like the preceding, this dam has been in service for several years. The cost, including the foundations, which had to be carried to a great depth by the use of compressed air, reached 16 515 francs per linear meter.

These two fine works, all the details of which were studied with scrupulous care, already serve as models for foreigners; they mark a new era in the canalization of rivers, and maintain the rank assigned to our engineers in this essentially French work of the construction of movable dams.

The Saône.—The Saône and the Rhône constitute together one of our great fluvial arteries. The Saône is entirely canalized for a length of 374 km. In the upper part of its course it is connected by the Canal of

the East with the system of navigable ways in the north and east of France. Fixed and movable dams on the Poirée system assure it a depth of 2.20 m. The locks above Gray have the normal dimensions fixed by the law of 1879, and from Gray to Verdun-sur-Saône, slightly larger dimensions.

In the lower part, below Verdun, the system is different; navigation is carried on by large convoys, and the locks, 160 m. long by 16 m. wide, allow of taking in a complete tow. The dams, six in number, including that of La Mulatière at Lyons, are formed of a navigable pass with Chanoine wickets, and of a weir with Poirée trestles. The minimum depth is 2 m., but the effective depth is generally greater.

Although finished since 1878, the works of the Saône were for the greater part constructed before that date. Among those of most recent execution there may be noted the dam of La Mulatière, built at Lyons by M. Pasqueau, Engineer-in-Chief, at the confluence of the Rhône and the Saône, on a system slightly different from that of the Chanoine dam. It is located at a pass which is, at the same time, broad and deep, where the use of the trip-bar was hardly practicable, and where special difficulties occurred from the nearness of the Rhône. M. Pasqueau has done away with this delicate part, and assured the manœuvre by means of a heurter, or supporting-block, with two notches.

To lower the dam in this new system it is only necessary to draw the breech chain until the prop comes to the second notch. The vertical plane oblique to the axis, which is formed by the lateral face of this notch, causes the prop to fall into the groove, and the wicket, held by its chain, comes gently to rest upon the platform. This modification secures, besides the suppression of a part sometimes difficult to control, the possibility of closing passages of a great width by Chanoine wickets, without which the opening would be limited by the length of the trip-bar. It is thus that the passage of La Mulatière, 103.6 m., could be closed.

This valuable advantage, joined to the facility of working of the Chanoine wickets, has induced Colonel Merrill, of the U. S. Engineers, to adopt this system in preference to all others upon the Ohio, where its use has been greatly extended in recent years. The scale is considerably enlarged, having regard to the dimensions of the American river; but the system is that of the Chanoine-Pasqueau dam, the first application of which was made at La Mulatière.

The Rhône.—The Rhône, whose excessive slope rendered its canalization difficult if not impracticable, offers the single example in France of the unobstructed improvement of a large river above its maritime portion. The regularization has been obtained by M. Jacquet, Inspector-General, and M. Girardon, Engineer-in-Chief, by means of longitudinal dykes of rip-rap, of spurs connecting them with the banks, and of dykes completely submerged, which, crossing the river in the deep places, correct the irregularities of the bottom and fix the depth of the channel. The cost has exceeded 40 000 000 francs. These works, without a single dam upon the Rhône, have been the means of giving a draft of 1.60 m. during 345 days of the year, on 290 of which a draft of 2.00 m. was available, of increasing the capacity of the boats by 24%, and have also enabled them to navigate with greater ease and without other means of traction than their own engines.

Navigable Canals.

Reconstruction of Locks; Elevator of Fontinettes.—Upon the canals the carrying out of the programme of 1879 has involved the reconstruction or enlargement of a considerable number of locks. The difficulty of carrying out this operation with the flights of locks on certain canals, and the opportunity thus presented of eliminating them, wholly or in part, have conspired to the construction of works designed to overcome greater lifts than in the past.

One of the most important of these works is the elevator of Fontinettes upon the canal of Neuffossé. Proposed at first by M. Bertin, Inspector-General, it was subsequently studied and executed by M. Gruson, Engineer-in-Chief. The elevator replaces five locks, which overcame an elevation of 13.13 m. It was copied from that already in use in England at Anderton, for small boats with loads of not over 80 to 100 tons, while that of Fontinettes receives boats of 300 tons. Reduced to its essential parts, it is composed of two caissons or metallic troughs, filled with water, in which the boats float. Each trough is fixed upon the top of a single piston, which works in the cylinder of a hydraulic press, installed at the center of a shaft. The two presses communicate by means of a conduit furnished with a valve in order to isolate them at will. At the bottom and top of their course the troughs can be connected with the lower level or the upper level of the canal as the case may be. Large gates, with

which the troughs and the levels are supplied at their extremities, permit of establishing or intercepting this communication. Three square towers built of masonry carry guides which direct the moving troughs in their course.

The machinery comprises two turbines run by water from the upper level; one of them serves to charge an accumulator of 1 200 liters capacity; the other drives an air compressor. The hydraulic presses, which constitute the most important part of this system, are 15.68 m. high and 2.08 m. interior diameter. They are composed of steel rings superposed each 0.155 m. high and 0.06 m. thick; a continuous lining of copper 3 mm. thick insures tightness.

The elevator was put in service in April, 1888. The time required to pass two boats, the one ascending, the other descending, is, on an average, 26 minutes. The total weight to be raised reaches almost 800 tons. The cost has reached 1 870 000 francs.

In the same line several French engineers, notably MM. Peslin and Flamant, have studied projects with inclined planes designed for boats of 300 tons. These projects present ingenious arrangements, but none of them have yet been put in execution.

Locks of High Lift; Canal of the Center.—In the different applications of mechanics to the elevation of boats by the vertical elevators, or inclined planes, the art of construction has reached, if, indeed, it has not passed, the prudent limits of the resistance of materials. Struck with this danger, other engineers have sought to resolve the same problem in a simpler and more practical manner by the employment of locks with high lifts. This solution is the one which has been adopted upon the Canal of the Center. The new locks of this canal have a lift of 5.20 m.; they have been justified by the same wants and have responded to the same necessities; they replace locks of less than half the lift, of which the surroundings did not permit the lengthening, and where it has been desirable to reduce the number in order to facilitate navigation.

The filling and emptying is controlled by means of cylindrical gates, the fixed part of which is built into the masonry of the side walls, and the moving part, operated by a vertical rod, is entirely supported by the fixed cover. The movable part receives only pressures which are in equilibrium, and consequently is operated with the same facility whatever may be the height of the lift. Water intro-

duced for filling by the head valves is distributed by lateral passages throughout the whole extent of the chamber, to which the depth of 2.60 m. has been given for a normal draft of 2 m. In emptying, the movement is reversed by the tail valves. By this method, the filling or emptying is done in 3 minutes and 15 seconds. The velocity of ascent or descent of boats in the chamber is 1.62 m. per minute; it is accomplished with very little agitation and without the least danger to the boat. The gates are closed by two abutting leaves protected by iron and galvanized steel. The cost per lock was 120 000 francs.

This elegant solution is due to M. Fontaine, Engineer-in-Chief and his skillful co-laborers. There is no doubt that it is susceptible of numerous applications; one application has been realized quite recently upon the Canal St. Denis.

New Locks of the Canal St. Denis.—This canal, which connects the port of Villette, the most important of Paris, with the Seine, has just been completely transformed. At the same time its depth was increased, like that of the Seine, to 3.20 m., and all the locks have been rebuilt. The new locks contain two chambers, the one of regulation type for canal-boats, the other of larger size for those of the Seine. They are provided with cylindrical valves of the same system as those upon the Canal of the Center. The gates are composed of a single leaf, a metallic body, with a wooden edge, turning around a vertical axis. They are operated by a little turbine run by the fall of the locks. When they are open, they drop back into a recess in the wall which separates the two chambers. This wall contains the passages for filling and emptying the chambers, the turbine, the water pipes, and all the apparatus for working; all the equipment is concentrated here, and the outside walls remain free for circulation.

As upon the Canal of the Center, advantage has been taken of the reconstruction of the locks, to diminish their number, by augmenting their lift. But they have gone farther in this direction and have given to one of them a lift of 10 m. This exceptional lift required some special precautions. In the ordinary system, the tail gates would have attained an excessive height, which would have rendered their construction difficult and their movement very laborious. In order to reduce this height, a masonry shield was constructed at the lower end of the lock which unites the two side walls, for the support (when closed) of the upper edge of the gate, which is of a single piece. Below this

shield there is reserved the necessary height for the passage of boats, and it has thus been possible to bring the dimensions of the gate to those which have been established by practice. As to the head gate, its height was determined by that of the lock wall.

This large lock is also provided with cylindrical valves for filling and emptying the chamber, and with a turbine for working the gates. There is, too, an equalizing basin designed to economize the water used in lockage. Put in service in 1892, it works with all the regularity desirable.

This remarkable work was designed and executed by M. Humblot, Inspector-General and M. Renaud, Engineer.

These examples demonstrate the possibility of overcoming by locks lifts which were formerly regarded as impossible. This simple economical solution, exempt from dangers, permits the difficulties which flights of locks bring to navigation to be overcome without recourse to mechanical appliances, and constitutes the most recent and important progress which has been realized by French engineers in the construction of canals.

Increase in Depth.—The programme of 1878 had more in view than the unification of the type of locks. According to the law of August 5th, 1879, the depth which, in most of the old canals, was only 1.60 m., and sometimes less, was to be increased to 2 m., in all those which were classed as principal lines of navigation. In fact, they have generally been given a depth of 2.20 m., in order to obtain an effective depth of 2 m., in spite of the deposits which may form in the levels, or the inevitable variations of the water level. This second operation has not been less laborious than the preceding, for it required the general raising of the banks, that of all the structures, and the elevation of most of the bridges.

Aqueduct of Briare.—Among the new works designed to procure this depth, the most important is the aqueduct of Briare over the Loire.

At present the canals which constitute the great line of navigation from Paris to Lyons, by way of Bourbonnais, are separated by the Loire, the crossing of which is made at the level of the river. In spite of the channels and improvements constructed a long time ago, during most of the year this crossing offers a totally insufficient depth; moreover, it is not free from danger when there are floods in the river, and it cannot then be considered as a line of the first order.

It has, therefore, been decided to construct an aqueduct 2.20 m. in depth, placed above the highest floods of the Loire, and connected on the opposite banks of the river with the existing canals by branches, which make the total length of the junction level 19 km. This bridge, 600 m. long, consists of 15 spans of 40 m. each. The trunk is entirely metallic; it is supported by two straight continuous girders, 7.25 m. apart in the clear, connected by cross-bracing; the tow-paths are supported by outside brackets. The whole work is designed to be built of steel; it is now in process of construction, and will probably be finished next year. The cost is estimated at 3 000 000 francs, and it will be increased by the approaches to more than 7 000 000 francs. It will be one of the most important aqueducts, and at the same time the largest application of steel to this kind of construction.

Water Supply.—These different improvements, the general increase in depth, the necessity of securing regularity of transportation during the dry season, and the development of traffic have required a very notable increase in the water supply upon most of the canals. In order to attain this end, various methods have been adopted. When circumstances permitted, the increased supply has been obtained by the construction of new reservoirs.

Among such works, that of Torcy-Neuf, designed for the Canal of the Center, merits particular mention. Its area is 166 hectares; the maximum height of the bank is 14.50 m., and the capacity 9 000 000 cu. m. The dam is formed of sandy clay, thoroughly compressed by a 500 km. steam-roller, and faced on the water side by masonry arranged in the form of steps. This reservoir presents a new and characteristic arrangement in its intake tower, which is built inside the reservoir at the foot of the dam. The interior of the tower forms a vertical shaft into which the intake valves, three in number, open 4.80 m. above one another. This shaft also receives the overflow at the top, and opens at the bottom into a waste conduit, which passes through the dam. The tower is reached by a little metallic footbridge.

This arrangement avoids the danger of infiltration, and the expense of a waste-weir over the top of the earth dam; the dam is pierced only at the bottom by the waste conduit, and all the rest forms a stable and homogeneous mass, in which no masonry is interposed.

The cost of this work was about 2 233 000 francs.

In cases where the permeability of the soil or local circumstances

prevent the construction of a reservoir, water has been supplied by powerful pumps from a neighboring river, lifting it to the canal. Several large plants of this kind for newly constructed canals have already been mentioned. The most important of these, the two groups of machines of Toul and of Vacon, contribute both to the supply of the Canal of the East, recently built, and to that of an older water-way, the canal from the Marne to the Rhine, the supply of which had become insufficient. It has incurred a total expense of 2 884 000 francs.

In the absence of reservoirs, such machines offer a valuable means of supplying the deficit. For the same object it is often desirable where it can be done, to reduce the leakage of canals. The method habitually employed in doing this consists in the use of a concrete revetment from 15 to 20 cm. thick, with which the bottom and sides of the channel are covered. Small openings furnished with valves permit an exterior pressure in opposition to the pressure of the water in the canal when necessary. This mode of tightening, due to M. Malézieux, Inspector-General, is already old and established by long practice. But it has received new and numerous applications in the last few years, notably upon the canal from the Marne to the Rhine, and the other canals of the region of the east.

It is by these various methods that we have become able to fulfill the new requirements of water supply. The improvement of the supply has required long and careful researches and difficult constructions, and it is not exceeded either in cost or in results obtained, by the other improvements of which it constitutes the necessary complement.

Chapter 3.—Traction.

In France, the mode of traction most used is towage by horses; this is the consequence of the predominance of canals in the network of navigable ways in this country. While continuing the employment of horses, the system upon the most traveled canals of the north, and upon the great line of navigation from Belgium to Paris, has been improved by the organization of regular relays established by the State itself by virtue of a decree of June 19th, 1875.

Each of these routes is divided into sections of 12 to 18 km., and the operation of each section is let for six years to a contractor by bidding. The towage thus organized is obligatory on all loaded boats,

as well on the ascent as on the descent, with the exception of boats propelled or towed by steam. The contractors for towage thus enjoy a veritable monopoly. On the other hand, they are required to tow the boats without any delay, with a velocity of 2 km. per hour. They are also required to add at the entrance and exit of locks, enough horses to hasten this double operation as much as possible.

The rates of towage are fixed per ton and per kilometer, according to the rates determined by the bidding. These prices apply both to canals and to canalized rivers, and include, at the same time, a tax for the possible tonnage of the hull and a tax proportional to the actual loading. They are, both together, from 0.0024 franc to 0.0036 franc per kilometer-ton on the descent, and from 0.0031 franc to 0.0058 franc on the ascent.

This organization allows the regular service of a traffic, which, on certain sections of the canals, reaches 3 500 000 tons per year. The constraint which it presents to liberty of towage is caused by the necessity of avoiding any retardation upon much-frequented water-ways, and of preventing encumbrances prejudicial to the common interest. The results obtained fully justify this measure.

For a long time, numerous investigations have been made, in order to substitute mechanical traction applied upon one of the banks for traction by horses. But the system of funicular towage, recently proposed by M. Maurice Lévy, is the only one which has resulted in anything practical. Briefly, in its essential parts, this system consists in the use of an endless cable moved by a fixed motor. The two portions of the cable run, one along the right, the other along the left, of the water-way upon pulleys carried by supports fixed outside the tow-path. The boats are attached singly to the one or the other of these portions according to the direction of the journey; the cable consequently tows up stream and down stream simultaneously.

This system, though very simple in theory, presents in practice serious difficulties, which have been happily overcome by M. Maurice Lévy. The cable is of metal and has been intentionally made very heavy; it weighs 3.65 kg. per linear meter. It is mounted with a tension of 5 tons for each portion, which brings the load upon the tightener to 10 tons and a permanent tension upon the steel strands of the cable of 5 kg. per square millimeter. This strong tension maintains the oscillations of the cable both horizontally and vertically,

within small limits. External forces, oblique traction, and the irregularity of the pull of the tow rope may be taken as quantities which may be neglected.

The supports are placed at intervals of 70 to 80 m.; pulleys of proper form and inclination guide the cable as well on curves as on straight lines; the grooves in the rims of the pulleys prevent the tow rope from disengaging from the cable as it passes over them. Certain ingenious arrangements give complete facility to boats to attach or detach at will without interrupting the motion of the system, and at the same time leave the cable free to rotate upon its axis, which is one of the results of its motion and which constitutes one of the principal difficulties which inventors have labored to overcome.

The most convenient velocity is from 2 500 m. to 2 800 m. per hour. But it offers a regularity and a constancy of motion which cannot be attained with living motors; on account of this circumstance, the time of passage can be reduced one-half.

This system of funicular towage has been installed and kept in service for two years on trial on the canals St. Maur and St. Maurice, near Paris. Following the results of this trial, the administration is prepared to make a first important application in the tunnel of Mont-de-Billy, upon the canal from the Aisne to the Marne.

As to the cost of traction, it depends on the traffic of the canal, since in this system the costs of installation and of operation are almost the same whatever may be the traffic. It is admitted that they will vary from 0.0044 franc per kilometer-ton, for a traffic of 1 000 000 tons, to 0.0016 franc for 3 000 000 tons, per year.

The passing through a canal tunnel, which presents a contracted passage of great length, always constitutes an obstacle to traction. For a long time towage by submerged chain, which permits a convoy of boats to pass through, has been in use. But the velocity is small on account of the resistance which the water offers to the passage of the convoy; the ventilation is insufficient, and it becomes necessary to take special precautions to avoid the emission of smoke. On this account, M. Holtz, Engineer-in-Chief, has used in the tunnel of Mauvages, 5 km. long, on the canal from the Marne to the Rhine, engines of the Traneq system, working without fire by means of steam reservoirs placed on the towboat. Outside the tunnel, steam is forced into these reservoirs at a high pressure and is used, during the journey

through the tunnel, in operating the steam motor. This system, which has been in service about 10 years, has given good results.

More recently, M. Galliot, Engineer, has proposed an elegant solution, founded on the use of electricity, for passing through the tunnel of Pouilly, upon the Burgundy canal. His project for electric towing has received the approbation of the administration, and should soon be put in operation. It is as follows: The water supply of the canal, received in the summit level where the tunnel occurs, will operate a turbine at each of the locks at the ends of the level; one of them will be of 21 H. P., the other of 14 H. P. Each turbine will run a dynamo which will each give a current of 16 ampères; the tensions will be 552 volts for one, and 368 volts for the other. These dynamos will be coupled for tension.

The motor will be placed on a small towboat of 12 tons displacement and will receive 16 ampères with a tension of 835 volts.

The line will consist of three conductors of silicon-bronze wire, 7.2 mm. in diameter. The current will be taken by means of jointed supports rising from the boat and making contact by a trolley upon the wire.

Finally, the towboat motor will turn by means of a double gearing the sprocket wheels, which will be mounted in such a manner as to utilize the towing chain. These arrangements will be completed by accumulators, which will be placed on board the boat, to correct the irregularities which may occur from variations in the number of boats to be towed.

Upon the rivers mechanical traction by means of towboats, tugs, or steamboats is generally substituted for towing by horses. These methods have been known for a long time; the most recent innovation consists in the utilization of electricity, but in a very different manner from the preceding.

We know that in towing by a submerged chain, as it is ordinarily practiced, it is necessary to take several turns of the chain about the winding drums of the towboat, the number being sufficiently large (four or five half turns on each drum), so that the adhesion shall be equal to the necessary force of traction. This requirement presents numerous inconveniences, and produces a rigidity of connection between the towboat and the chain which does not permit of freeing one from the other easily. Now, experience has proved that if the tow-

boat has a superiority over tugs on the ascent, these latter have the advantage on the descent, and the towboat usually descends empty.

The Director of Towing on the lower Seine and the Oise, M. de Bovet, has sought to avoid this rigidity by the use of a magnetic pulley, which he has substituted for the winding-drums. In this system, the chain passes only once over the groove of the pulley; adhesion is obtained by an electric current, which magnetizes the groove and which can be turned on or off at will. It thus becomes easy to disengage the towboat from its chain. The boat, constructed like a tug, is supplied with a towing apparatus which it uses only on the ascent. It can leave the chain at any point of its course, and descend as a tug.

After investigating for several years, M. de Bovet seems to have solved in a practical manner the numerous difficulties of detail which this problem presents ; the new towboat tug, constructed on this system, will be put in regular service on the Seine and Oise in the course of the year 1893.

We see that on all sides, engineers and constructors are seeking to improve the means of traction, and that important progress has been realized in the last few years. In the same general direction, several engineers have made theoretical and experimental studies of the greatest interest. There may be noted, among others, those of M. de Mas, Engineer-in-Chief, and those of MM. Caméré and Clerc.

The first is especially interested in determining the different elements which enter into the resistance of a boat to traction ; given the immersion, the form of the immersed section, and the nature of the surfaces in contact with the water, to be able to separate the influence of each of these elements in the total traction. The other two have had more particularly in view experimental researches into the tractive force in the different levels of a canalized river, so as to find out the easiest passages, and those, on the contrary, where, on account of a contraction of the bed of the river, or for some other cause, the power required is very great.

In conclusion, all the efforts converge not only toward the improvement of the navigable water-ways, but also toward their better utilization by perfecting the methods of traction.

SECTION III.—EXPENSES AND TRAFFIC.

CHAPTER 1.—EXPENSES; GENERAL CONSIDERATIONS.

After having thus described the principal betterments carried out upon our network of water-ways since 1876, and before seeking to show the results obtained, that is to say, the influence exercised by the completed work upon the development of the circulation and the new facilities of every nature which they have assured, it is believed it will be useful to indicate what the cost of these works has been.

From 1876 to 1891, the amount expended under the title of "Works for the Establishment and Improvement of Navigable Water-Ways," was, altogether, 564 000 000 francs. But this round number, applicable to the whole network, includes operations which, although really carried on upon navigable rivers and canals, cannot be considered as pertaining solely to the improvement of navigation. These figures present some discrepancies, especially if one wishes to bring together those which measure the increase in traffic due entirely to the new works.

	Francs.
Let us consider first that portion of the expenses pertaining to the navigable water-ways in the south, southwest and west, and a portion of the center; water-ways which ought not to be included, or which have not been included, in the work of unification. The greater portion of the expenses which concern them have been on works executed in the maritime portions of the Loire, the Garonne and the Charente, which pertain exclusively to maritime navigation and, consequently, ought not to be charged to interior navigation. The sum to be deducted under this head amounts to....................	83 000 000
It is likewise reasonable to deduct a portion of the expenses made for the betterment of the maritime portion of the Seine which, properly speaking, constitutes the channel of access to the port of Rouen, and where the depth, even before these improvements had been commenced, was sufficient for the inland boats. Under this head there should be deducted an expense of...	14 000 000

	Francs.
Brought forward	97 000 000
We should make a separate account for the waterways in the course of construction or improvement, and which have been, consequently, unable to show the growth in circulation and traffic which the works in course of execution ought to assure to them; these, for canals still in the course of construction, amount to	66 000 000
and for the lines in course of improvement only, amount to	55 000 000
Altogether, the deductions to be made are	218 000 000
If we subtract this sum from the total previously indicated, we find that the actual expenses really pertaining to the parts of the network on which the improvements undertaken under the laws mentioned at the beginning of this memoir are now completed, amounted on January 1st, 1892, to	346 000 000

These will be considered for each of the great lines in the chapters which are devoted to them, respectively.

Chapter 2.—Traffic; General Considerations.

In order to establish, year by year, useful comparisons of traffic, concerning the system of routes of communication, the best unit is the kilometer-ton, that is to say, the ton of 1 000 kg. moved 1 km. The "kilometric tonnage" is the sum of the products obtained by multiplying the weight (in tons) of each cargo by the number of kilometers which it travels.

In 1876, the kilometric tonnage of the navigable ways of France was	1 953 000 000	kilometric tons.
In 1891 it had increased to	3 537 000 000	" "
Difference	1 584 000 000	" "
Making an increase of	81%.	

This increase being for the whole system, it was affected by the unfavorable results on certain parts of the system upon which the

work of unification had not been carried out; on some of them, far from concurring in the general increase, there was a diminution in their special circulation. If we consider the single lines where the boats transport ores, and which already had a depth of 2 m., the results are infinitely more satisfactory. This is shown in the following table:

	Length in kilometers.	Kilometer tonnage (in thousands of kilometer-tons.		Increase.	
		1876.	1891.	Actual.	Per cent.
Seine (from Montereau to Rouen)....	344	289 607	639 864	350 257	121
Line from Belgium (from Conflans to the Belgian frontier)............	299	439 991	731 272	291 281	66
Lines from the Escaut to parts of the North Sea......................	411	174 516	389 356	214 840	123
Line from Paris to the German frontier)........................	452	164 078	324 578	160 500	98
Canal of l'Est (from Givet to Corre)..	432	344	197 048	196 704	
Junction of lines from the east and north (canals from the Oise to the Aisne, lateral to the Aisne, Aisne to the Marne).....................	157	45 706	93 157	47 451	104
The Saône (from Corre to Lyons)	374	69 162	102 343	33 181	48
Totals.........................	2 499	1 183 404	2 477 618	1 294 214	109

Thus, upon these different portions of the system, the only ones which are of interest in this study, the increase from 1876 was 109 per cent. It should be remembered, however, that upon many portions of the lines given in the preceding table, the completion of the work is of very recent date, and that the improvements realized are far from having yet produced their entire effect upon the development of traffic. There is no doubt that after the completion of the works of unification of the lines from Paris to Lyons by Bourbonnais and Burgundy, there will be shown, not only upon these lines, but upon all the routes which are in communication with them, a development of traffic no less remarkable, and no less rapid.

The increase of the kilometer tonnage gives only one side of the aspect of the circulation. Previously to the period which has been considered, the diversity of the depths, and that of the dimensions of the structures, formed serious obstacles to long trips. The waterways were most often utilized for local and restricted circulation only.

The object of the unification of the system was to permit transportation to long distances without lightening or trans-shipment. It is, in fact, only for long journeys and important cargoes that navigation produces its maximum efficiency. The annual cost of a boat capable of carrying several hundred tons of freight is not much greater than that of a boat of small dimensions. The cost *en route*, aside from traction, especially for boats which do not carry their own propellers, is, so to speak, insignificant. The really important expenses are those which attach to each special operation of transportation at departure and arrival; loading, unloading, supervision, storage, etc., which in English are designated by the name of "terminal charges." Now, if the expenses for material and labor are distributed over all the operations of transportation effected in the year, the terminal charges will be distributed over the units of traffic to which these charges belong, that is to say, over the total kilometer-tons which make up the operation. Though very heavy, if confined to a journey of a few kilometers, the cost becomes much less if it is to be distributed over the hundreds of kilometers of an extended trip.

In fact, for distances of a few kilometers, and at least for places of production and consumption, situated upon the banks of the same water-way, navigation cannot even compete with carting. The same causes of inferiority are found for trips of average length, with regard to competition by railways, which, by reason of their flexibility in alignment, present a real superiority over water-ways, and adapt themselves more easily to branch lines for industrial growth.

On account of these different considerations, and in order to appreciate the results of the work for the unification of the navigation system, it is very important to show the increase of the average journey effected upon the system. The comparison unfortunately cannot be established with that of the year 1876, adopted as the starting point for this study. At that time the annual statistics did not give separately the effective weights of cargoes, but the movements by separate routes only. We would have thus for each river or canal the number of tons which were moved over it, but those elements of traffic which pass successively over several water-ways, in order to complete their journey, cannot be summed up without adding them more than once. It is only since 1881 that the traffic accounts have been kept, not only by routes, but also by the separate cargoes shipped.

In 1881 the total weight of cargoes shipped reached	19 740 000	tons.
In 1891, the same total reached......	24 167 000	".
The actual increment was	4 427 000	"
The percentage of increase is	22	per cent.
On the other hand, the total kilometric tonnage reached in 1881 ..	2 174 000 000	tons.
It reached in 1891..................	3 536 000 000	"
The actual increment was	1 362 000 000	"
The percentage increase was.........	62	per cent.

The increment was thus 22% on the effective tonnage (weight of cargoes), and 62% on the kilometer-tonnage.

The progress realized was then mainly in the length of trips; or, in other words, what the new cargoes gained by the navigable way correspond to the lengthening of the haul, profiting, consequently, by the economy which interior navigation secures by long journeys.

A very simple calculation will make clear the progress realized in this direction. The increment of 4 427 000 tons of cargo corresponds to an increase of 1 362 000 000 km.-tons. If we admit that the old streams themselves have not been modified, the average length of the new journey would be 307 km., while the average journey in 1881, 10 years previously, was only 110 km. This result demonstrates the efficiency of the works already completed.

If we recall the facts that the completion of the works of unification is, for the greater part of the improved water-ways, of a very recent date, and that especially the works undertaken on the lines of the center are not yet finished, and have as yet been able to exercise no influence upon the circulation, we may predict for the near future a new and considerable lengthening of the average journey, and important progress of navigable water-ways in the line of the service which they are best able to render.

The unification of the depths and of the dimensions of the navigation works could be made efficacious only by bringing about a corresponding change in the *materiel* or the fleet, and of its means of traction—boats and motors.

The interior navigation fleet in France is composed of the most incongruous elements, and a calculation of average based upon capa-

cities and forms and also upon methods of use which are not correlated would not be of interest. Some general indications in this respect, however, will not be amiss. A general enumeration of the fleet in France was made for the first time in 1887, and revised in 1891. The comparison of the results at these two dates, which, however, are only separated by a space of four years, nevertheless furnishes valuable indications, and shows with what enthusiasm the business of transportation has hastened to profit by the new facilities given to the circulation of boats of larger dimensions and of more perfect forms, and to the employment of more economical motors.

The total of freight boats enumerated was:

In 1887	15 730	boats of net tonnage		...	2 713 847
In 1891	15 925	"	"	...	2 996 230
An increase in favor of 1891 of	195	"	"	...	282 383

The increase in net tonnage was about 10 per cent. But if one extends the comparison to the types of boats in use when the dimensions of the programme of unification were adopted, we arrive at much more favorable results. The number of boats 38.50 m. long and more was:

In 1887	933	boats with total net tonnage of			...	342 933
In 1891	2 016	"	"	"	...	747 758
Increase	1 083	"	"	"	...	404 825

The increase of boats of the new type amounts to 54 %, whether one considers the number or the capacity. The force employed on the fleet received, in the same time, an increment corresponding to the increase of the *materiel* and the activity of transportation (6% in four years). The greater part of the *materiel* of the fleet is composed of flat boats, generally of wood, and put in motion by an outside motor.

Steamboats do not accommodate themselves well to canal navigation. Short levels and flights of locks slacken the speed, and do not permit the steam motor to be used sufficiently to render it economical. It is the same as regards steam towing. Thus, steamboats and towboats are concentrated upon rivers and streams—there only where the circulation is free, and where they meet levels of sufficient length (Seine, Rhône, Saône).

In order to give an idea of the results obtained by the transformation of the system of interior navigation, it is not sufficient to present the increments of circulation. Progress, in the matter of the means of transportation, results from multiple conditions. There may be cited the economy due to lowering the price of freight, to increasing rapidity, to greater regularity, to the diminution of the risks *en route*, to greater facilities on arrival and departure for loading and unloading, and for transferring freight to the connecting routes which take it to the ports of departure or to its final destination.

These various conditions cannot readily be expressed in statistical form or in a synthetic sketch. We shall, nevertheless, see further on that, especially where unification has permitted new routes to be established and places of production to extend their power of expansion, a progressive reduction in freight rates has occurred.

Chapter 3.—The Seine.

This chapter will deal only with the portion of the Seine comprised between Montereau and Rouen, since below that city it belongs principally to maritime navigation. The chapter will be divided into two sections; the first treating of the portion from Montereau to Paris, the second of that from Paris to Rouen.

Section I. *The Seine from Montereau to Paris.*—As early as 1875, the normal depth of the Seine from Montereau to Paris (98 km.) was 1.60 m. The work of increasing this depth to 2 m. was only finished in 1884. Nevertheless, the commerce since 1876 has been of real importance. Expressed in kilometer-tons, it was more than 80 000 000; in 1884 it was 112 000 000 and in 1891 it was 160 000 000. In seven years it had gained 48 000 000 km.-tons, or about 33 per cent. It has doubled in 17 years.

At the same time, the average rate on freight, which, in 1876, was 0.03 franc per kilometer-ton, was lowered in 1891 to 0.017 franc. These average values are taken from through shipments extending beyond the Upper Seine, and in applying them to a trip made upon the latter, its share, *pro rata*, is used. If it were possible to separate the part belonging to this section of the river for the long trips, we would certainly arrive at a freight rate lower than that which has just been given.

If we consider only the length and the width of locks, the upper

Seine could be frequented by boats of considerable dimensions; barges of 1 000 tons capacity are already in use, but these are only the exceptions. As a nearly general rule, it may be said that the boats which frequent the Upper Seine are *en route* to or from provinces on the affluent lines. Thus, their dimensions, their displacement and, consequently, their net loading, depend much more upon the conditions of navigation upon the affluent water-ways than upon those of the Upper Seine. This is the explanation of the relatively small figures which we find for the average cargo; still, considerable progress has been realized in 15 years. In 1876 the average boat load was: descending, 122 tons; ascending, 78 tons; average of both directions, 111 tons. In 1891 it had attained: descending, 178 tons; ascending, 142 tons; in both directions, 166 tons.

It should not be forgotten that canal-boats of the legal type are capable of taking a net load of 300 tons, and in spite of the fact that the capacity of the boats could have been immediately increased 15 years ago, the average load in 1891 was not much over one-half the maximum load of canal-boats of the legal type. It is, indeed, in the methods of traction that the work of improvement of the Seine has produced a true revolution in permitting the regular use of screw-tugs.

In 1876, as in 1891, nearly all the common modes of traction could be seen on the Upper Seine; towage by submerged chain, by tugs, by horses or by men; a few boats and rafts descended in the current by means of oars, poles and even, rarely, by the wind. In 1876 most of the towage, about 80% of the total, was by submerged chain. In 1891 the proportion of the total tonnage drawn by the chain had decreased to 49%, 35%, and even 27%, according to the portion of the route considered, while the proportion towed by boats had increased to 44%, 55%, and even 71 per cent.

This competition has resulted in a considerable decrease in the cost of traction. In 1876 the current rates for towage per kilometer were established upon the following basis :

	Francs.
Ascent per ton of possible burden per kilometer..	0.0035
Ascent per ton of actual burden per kilometer....	0.015
Descent per ton of possible burden per kilometer.	0.000875
Descent per ton of actual burden per kilometer...	0.00375

Since 1891 these rates have been reduced 20%, and now only consti-

tute maxima susceptible of considerable reductions, according to the condition of the water and the demands of commerce. It is not too much to affirm that the price of traction has gone down more than one-half.

The cost of the works executed under the law of June 13th, 1878, for increasing the depth of the Upper Seine to 2 m., and for various other improvements, has risen to 6 000 000 francs.

The Seine, from Paris to Rouen.—In its present condition, the lower Seine, including the Paris slack-water level, has a length of 250 km., divided into 10 levels. The works have already been considered in this paper, and have been put in service as fast as completed. But it is only since September 15th, 1886, that the route has been open throughout to a depth of 3.20 m. In 1875 the total kilometer-tonnage of this section of the Seine was less than 200 000 000 km. In 1887 it had already reached 290 000 000 km.-tons, and in 1891, 480 000 000 km.-tons. The increase from 1875 is 140%, of which two-thirds apply to the last six years. Towage by horses, which still preserved some importance in 1875, had completely disappeared in 1891. The employment of steam was particularly developed on this part of the Seine. At the time when the enumerations for 1891 were completed, there were upon the Seine, between Paris (above) and Rouen, 32 freight boats, of a total capacity of 8 060 tons and 3 120 horse-power. Four years before there were only 30 freight boats, with a capacity of 6 211 tons and 1 816 horse-power. The tugs enumerated on the same sections were 54, with 7 465 H. P., in place of 48 tugs, with 4 024 H. P., in 1887. There were 14 submerged-chain towboats using 1 365 H. P., in place of 20 boats and 1 577 H. P. in 1887. The submerged chain lost ground. But this loss was compensated by a remarkable increase of freight boats and tugs. An analogous transformation has manifested itself in the *materiel* of ordinary boats (without motors); the dimensions have been increased, and the advance has not yet ceased.

Finally, the results of the transformations carried out in the technical conditions of the navigation of the lower Seine can be summed up as follows: By the construction of new dams of more perfect type, and the remodeling of the old ones, a minimum depth of 3.20 m. corresponding to a draft of 3 m. has been assured at all times between Paris and Rouen, without interruption, while in 1876 the depth frequently decreased in times of low water to less than the nominal 2

m., and sometimes even to less than 1.25 m. Towage from the tow-path may be said to have disappeared ; towage by submerged chain has lost its importance; and transportation by tugs and steamboats has very greatly increased ; the time of the trip from Rouen to Paris (ascent) has diminished about 20%, while the efficiency of the boats has sensibly increased, and has reached 80% for the ascent and 40% for the descent.

Many owners have been able to make improvements in their boats with a view of utilizing the depth of 3.20 m. Thus, at the present time, certain barges carry from 900 to 1 000 tons of freight, while, in 1876, the tonnage of the largest barges did not exceed 600 tons ; the steam-tugs have engines of 500 H. P., instead of 80 and 100 H. P., and sea-going steamers of 450 H. P. ascend as far as Paris with loads of about 500 tons.

Finally the comparison of the price of transportation for 1876 and for 1892 shows, for the entire distance from Paris to Rouen and return (243 km.), a diminution of 2.30 francs on the descent, or 47%, and 2.70 francs on the ascent, or 43%, corresponding to reductions of 0.009465 franc and 0.011111 franc per kilometer, respectively.

It is to be presumed that the price of transportation will experience new reductions from time to time, with the better utilization of the depth of 3.20 m., and of the boats navigating the lower Seine, and that the time is not far off when it will fall to 3 francs per ton on the ascent (0.0123 franc per kilometer-ton) and to 2 francs per ton on the descent (0.0082 franc per kilometer-ton), leaving out the express freights which represent only a small part of the traffic.

Chapter IV.—Principal Line from Paris toward Belgium (from the Confluence of the Seine and the Oise to the Belgian frontier, near Mons).

The length of this line, which includes both canalized rivers and canals, is about 283 km. The different sections offered ordinarily in 1876 a uniform depth of 2 m.; but the widths of the channel, the dimensions of the locks and the heights under the bridges were slow to respond to the conditions of the programme until late in 1879. Since then, the line has not only undergone transformations which conform to the work of unification, but it has received at the same time numerous improvements in detail.

These transformations have been executed by virtue of the laws of July 27th, 1880, and December 10th, 1886. All the improvements contemplated have not yet been realized. Important works, notably the doubling of locks, should be undertaken soon, in order to give passage to a traffic constantly increasing. The following table gives the traffic in 1875, 1885, and 1891, upon the different water-ways of which the line is composed:

	Length.	Kilometric Tonnage.			Per cent. increase since 1875.
		1875.	1885.	1891.	
	Kilometers.	Tons.			
Canal from Mons to Condé	5	4 200 000	3 449 000	3 341 000	— 24
Escaut	48	70 000 000	69 972 000	79 504 000	+ 13
St. Quentin Canal	93	175 000 000	221 805 000	305 802 000	+ 75
Canal along the Oise	34	65 000 000	81 917 000	83 731 000	+ 37
River Oise	104	140 000 000	195 635 000	247 738 000	+ 76
Totals		454 200 000	582 779 000	725 116 000	+ 60

At certain locks of the line there were passed, in 1891, more than 21 000 boats, having a total tonnage of over 3 500 000 tons. The improvements realized upon the line, and which have permitted this remarkable increase of traffic, have, moreover, rendered the traction of boats easier. At the same time that the speed of the boats has become sensibly more rapid (25 days in place of 32, in the total distance), the frequency of necessary stops and the length of delays of all kinds have been considerably reduced. The boatmen have been able, on this account, to double the number of their annual trips, which has diminished the general cost by one-half. This diminution, added to the economy which they realize in the cost of traction, has permitted them to reduce the freight charges from 15 to 20 per cent. The reduction would doubtless be greater if it were not for a considerable obstruction to the free play of competition upon the line. Besides, we ought, also, to consider in the profit realized by consignors and consignees the increased rapidity and facilities of every kind assured to commerce.

The improvement of this line has cost only 12 000 000 francs up to the present time.

Chapter 5.—System of the North and of Pas-de-Calais.

This system consists of 20 water-ways or sections, rivers and canals, measuring together 523 km. The most important collieries of France are concentrated in the departments of the north and of Pas-de-Calais. The routes which traverse them belong to the general system, and are in communication with Paris by the canal of the Sensée, which connects with the middle Escaut, and becomes thus in a manner an affluent of the line from Belgium toward Paris. The works of unification have been carried out under a series of distinct laws, promulgated from 1875 to 1884.

The kilometric tonnage of this system was 160 000 000 km.-tons in 1875. It has increased to 428 000 000 km.-tons in 1891. The actual increase is 260 000 000 km. tons. The percentage increase is more than 150 per cent. Certain lines share in this increase in such a manner as to merit special notice. These are:

The upper Deule, which touches the city of Lille (57 km.); its traffic has risen from 45 000 000 to almost 100 000 000 km.-tons.

The canal of the Sensée, a branch of the great line to Paris, the traffic of which has risen from 20 000 000 to 60 000 000 km.-tons.

The canal of Aire (44 km.), which connects the Deule with the canal from Neuffossé to La Lys; its traffic has risen from 25 000 000 km.-tons to 75 000 000.

As on the Belgian line, so on the routes of the north and of Pas-de-Calais, we find that the character of the boats has been much improved. Almost all the new boats have been built upon the type of 300 tons. A large number of old boats has been modified so as to conform to this type. Hand-towing, still common in 1875, has almost disappeared. Towage by horses has become the general rule, and the quality of the horses has been much improved. Upon a certain number of exceptional ways the towage has been organized by the administration, to the great profit of the fleet as to velocity and economy. At other points special steam towing with submerged chain has been established, and is very prosperous.

It is certain that all these causes united, as also the pains taken to reduce the necessary and accidental delays, have considerably diminished the losses of time which were so great before. The velocity of travel has been notably increased, and the boatman who in 1875 was hardly able to make three round trips per year between the colliery

basins of the north and Paris can easily make five to-day, provided he is active and provident.

The price of freight has not sensibly diminished upon this line; but as upon the line from Belgium, this is due to a lack of competition and also to the fact that under the old régime the principal water-ways, while inferior to the present ones, nevertheless permitted the circulation of boats having a capacity approaching that of the Flemish canal-boats. Transportation enterprises have more especially profited by the diminution in the cost of returning. But producers and consumers have found it also to their advantage, not only in the considerable increase of the capacity and frequenting of the ways, but also in the economy of time and the greater regularity of transportation.

The expenses devoted to the improvement of this system have reached 32 000 000 francs.

Chapter 6.—Line from Paris to the East.

This line runs from the mouth of the Marne, a little above Paris, to Charenton. It includes a part in the bed of the River Marne, canalized with locks for 179 km. Then 373 km. of canals. The Marne and the canal by its side form the principal portion. The canal from the Marne to the Rhine, which is found at the eastern extremity (210 km.), serves, especially in the neighborhood of Nancy, numerous industrial establishments situated upon its banks, notably blast furnaces, forges and foundries, iron mines, salt works, soda factories and chemical works.

The transformation of the line, where the depth has been increased to 2.20 m. and the locks lengthened to 38.50 m., has been effected by virtue of different decrees from 1878 to 1882. The transformation of the boats has followed closely upon that of the route, which has sensibly increased the power of transportation. It is principally in the last few years that the average tonnage of the boats has been increased.

The diminution of the time of passage, very noticeable on the canalized Marne, appeared of slight importance in the trip through the canal from the Marne to the Rhine. The improvements carried out have doubtless had the effect of preventing delay and of facilitating the passage and increasing the size of boats; but, on the contrary, the considerable increase of traffic upon the canal from the Marne to the Rhine has multiplied the causes of delays and blockades, espe-

cially at the locks, which are very numerous (113), and which, with the tunnels, require at least a third of the normal time of passage of boats. For a great number of trips, going from one part of the region of the east to another, we nevertheless find a real reduction. This reduction must be principally attributed to the opening of new routes. Thus the canalization of the Meuse (northern branch of the Canal of the East) has resulted in reducing to 20 or 22 days the trip from Nancy to the coal mines of Liége and Couillet in Belgium, which formerly occupied 40 days, when it was made by the routes of the north and of the Sambre. Likewise, the construction of the canal from the Oise to the Aisne has brought about a gain of 4 or 5 days in the trip from Nancy to the coal mines of the north of France.

There has been on this line a much more noticeable reduction in the price of freight than that which has taken place upon the lines described in the preceding chapters. From the collieries of the north to Nancy the cost of transportation of coal has fallen from 9.50 to 7.50 francs, and from Nancy to Paris from 9 to 6.50 francs. From Nancy to Lille, for salt and soda, the reduction is much greater, from 9.50 to 5 francs. It is not rare to-day to see the price of freight drop to 0.01, 0.009 and even 0.008, franc per km.-ton for certain kinds, such as pig iron and iron ore, transported as a return load by boats which have brought coal from the north of France or from Belgium to the metallurgical establishments in the basin of Nancy.

In order to bring out the progress realized upon this line, it only remains to give the comparison of the kilometric tonnage at three periods, 1875, 1880 and 1891. It may be remarked that from 1875 to 1880 the tonnage on this line had, without doubt, suffered a considerable depression from railroad competition. The upward movement only shows itself since the completion of the works.

	Kilometric Tonnage.		
	1875.	1880.	1891.
Canal from the Marne to the Rhine........	106 000 000	83 000 000	216 000 000
Canal along the Marne....................	27 000 000	27 000 000	57 000 009
Marne	21 000 000	25 000 000	51 000 000
Total..............................	154 000 000	135 000 000	324 000 000

The decrease in traffic from 1875 to 1880 was 12% ; from 1880 to 1891 it was 140 per cent. The cost of the work done on this line is 14 000 000 francs.

Chapter 7.—Canal of the East.

This is a new route, 432 km. long, designed to re-establish in our territory the economy of our system of navigable ways, which was considerably interrupted by the new frontiers imposed upon us by the war of 1870–71. It starts from the Belgian frontier at Givet, and connects with the Saône at Corre. There is nothing here for a comparison with the past. The traffic furnished by this route in 1891 was 198 000 000 km.-tons, a great part of which extends over the remainder of the system and comes in for a large part in the increase of traffic shown by the statistical figures already quoted.

This canal has contributed largely to the reduction of the average price of transportation, by favoring the lengthening of certain trips by water. Thus it makes it possible to bring to Creusot, for example, the castings of Meuthe and Moselle, which could not previously be brought there by rail at a reasonable price. The coals of Belgium and the north, of superior quality, have entirely supplanted Prussian coals in the Vosges ; the metamorphic sandstone paving stones of the Vosges are brought to Rouen, Calais and Dunkirk, replacing the original Belgian pavements.

Chapter 8.—Water-Ways Connecting the Canal of the East with the Lines from Paris to Belgium and from Paris to the East.

Three of these water-ways are old:

First.—The canal of Ardennes (88 km.), starting from Pont-à-Bar, upon the northern branch of the Canal of the East, and connecting at Vieux-les-Asfeld with the lateral canal of the Aisne, which latter, following along the river Aisne, connects with the line from Belgium to Paris.

Second.—The lateral canal of the Aisne (51 km.), followed by the canalized Aisne (59 km.), as mentioned above.

Third.—The canal from the Aisne to the Marne (58 km.), which connects the two preceding canals with the line from Paris to the East.

A fourth water-way constructed anew and opened only in 1890, the canal from the Oise to the Aisne (48 km.), has for its object the improvement of the connection by water between the north and the east of

France by procuring, with reference to the old distance, a reduction of 56 km., and in avoiding 61 km. of river navigation.

The work of improving the structures on the three old canals is nearly finished, and it has already brought manifest fruits. The boats of the northern lines, shallops and barges, ply there, and the average load has been increased 40 to 47%, with a corresponding reduction in the price of freight.

The velocity of boats on the open levels varies little, but the reduction of the time of lockage and the improvement of certain difficult passages have brought about a general diminution of the length of trips, so that the trip from Pont-à-Bar to Paris (369 km.) is made to-day in 12 days, in place of 15.

The traffic of the canal of the Ardennes has increased in a remarkable manner, notably since 1885. Like that of a part of the canal along the Aisne, this increase began in large part with the opening of the Canal of the East, and with that of the canal from the Oise to the Aisne. The opening of this last canal has brought about, moreover, a considerable shifting of traffic, as is shown by the following table for this and the other canals.

	1875.	1885.	1890.	1891.
Canal of the Ardennes	9 500 000	12 256 000	17 941 000	22 978 000
Canal along the Aisne	20 796 000	25 390 000	27 207 000	31 532 000
Canalized Aisne	36 856 000	40 203 000	23 818 000	9 149 000
Canal from the Oise to the Aisne	36 856 000	40 203 000	24 741 000	55 939 000
Total	67 152 000	77 849 000	93 507 000	119 598 000

If we consider the shortening produced by opening the canal from the Oise to the Aisne, the traffic of which has developed at the expense of that of the canalized Aisne and a part of the canal beside the Aisne, we shall see the remarkable increase of circulation upon these different lines. This increase is 142% for the canal of the Ardennes, which is the only one properly comparable.

The canal from the Aisne to the Marne (58 km.), which connects the preceding group of water-ways with the line from Paris to the East, has, like them, been improved.

Its traffic, throughout the whole course, changing with that of the routes which it connects, has risen from 27 261 000 km.-tons in 1875

to 32 416 000 in 1891. The proportional increase is 19 per cent. The conditions of velocity and of price have not materially varied on this canal.

The expenses contracted on the lines connecting the routes of the north and of the east have amounted to about 40 000 000 francs, of which 33 600 000 francs were for the construction of the canal from the Oise to the Aisne.

CHAPTER 9.—THE SAÔNE FROM CORRE TO LYONS.

The navigable Saône comprises three distinct sections: 1st, from Corre (junction of the Canal of the East) to St. Jean-de-Losne (mouth of the canal of Burgundy), 136 km.; 2d, from St. Jean-de-Losne to Barbe Island (above Lyons), 202 km.; 3d, from Barbe Island to the Rhône (Lyons slack-water level), 9 km.

The works of improvement were completed between 1882 and 1885; and in order to show the importance of the traffic, the kilometric tonnage in 1875, 1885, 1891 is given.

	1875.	1885.	1891.
First Section	5 329 000	22 259 000	30 259 000
Second Section } Third Section }	71 634 000	69 032 000	{ 69 787 000 { 2 296 000

The work of the canalization has reduced the distance by 25 km., which is to the disadvantage of the years 1887 and 1891, in this calculation.

The work of improvement of the Saône has brought important results so far as concerns the development of traffic, only upon the first section which joins the Canal of the East and receives the canal of Burgundy. The proportional increase for this section reaches nearly 500 per cent. It has thus become, so to speak, a new water-way.

Navigation is already established upon the Burgundy canal, where the locks have been lengthened. It is not so with the two lower sections which communicate with the Rhône, where the work of transformation is not yet finished, and with the line from Paris by Bourbonnais, where the completion of the work of unification will doubtless still require two or three years. However that may be, it should be stated that the conditions of navigation of the Saône have been very much improved. The average load of the ordinary boat, which in 1876 was

only 75 tons, had risen to 125 tons in 1891. Steam navigation is developing there. While in 1876 there were only 13 tugs and steamboats, having a total of 764 H. P., the number of these boats is now 24, and their horse-power 1 738. The work of improvement executed since 1876 has cost about 14 000 000 francs.

CHAPTER 10.—THE RHÔNE FROM LYONS TO ST. LOUIS (327 KM.).

Although the Rhône does not figure in the list of water-ways fulfilling the conditions of depth provided by the programme of 1879, the results obtained by means of the work thus far executed have been considerable. At the time when the works upon the Rhône were undertaken, navigation there was rapidly decreasing. Perhaps on no river had boating been so severely tried by the opening of railroads, and its ruin appeared so complete that people had become accustomed to consider navigation as a means of transportation practically condemned and destined to be entirely replaced by railroads.

At the time of the greatest development of navigation, before the victory of the railroads, transports were divided into three types: boats for the transportation of passengers and freight, lightly loaded on the descent, but taking the most important part of the traffic upon the ascent; boats descending with the current, and taking the principal part of the traffic upon the descent; finally, grapnel towboats descending without convoys, and ascending with empty or partially loaded boats, which comprised only a relatively small part of the upstream tonnage, because of the irregularity of their service.

Thus there were in fact two systems, one well adapted to the conditions of ascent, but stopped by low water, and bearing only a small traffic on the descent, the other irregular in its movement and not economical on the ascent on account of the magnitude of the resistances and the stoppage of the tugs by high water. It is evident that this was a cause of weakness which did not permit the boats to give a large return, and that the types least adapted for work in both directions would be less capable of adapting themselves to the new conditions created by the competition of railroads and of overcoming it. This is in fact what has taken place.

Navigation by descending with the current has been most extensively employed; this movement, which in 1884 amounted to 236 000 tons for the total distance between Lyons and Arles, had decreased to

33 000 tons before the law of 1878. It continued to decrease until the first improvements in the river were felt; the minimum was in 1880, and was 24 000 tons. Since then it has increased a little. This mode of navigation has lost its principal freight, coal, not only on account of its own imperfections, but also on account of the absence of all means of exchange between the river and the railroads which connect the Rhône with the colliery basins; it has found it anew, and notably in freightage of lime, and the traffic in this was brought up in 1891 to 38 000 tons.

Navigation by towing by the aid of grapnels in ascending has suffered the same decrease, and for the same reasons. Its traffic, which had reached 67 000 tons at one time, had fallen in 1878 to 5 700 tons. It has risen a little since. A new grapnel towboat, which was designed in view of the new conditions of the river, and which can be used with the highest water, has recently been tried. The movement by steam navigation (tugs) reached 14 000 tons in 1891.

Very different has been the situation of navigation by steamboats. They presented the double advantage of being able to run in both directions with a sufficiently great velocity; they suffered long delays caused by insufficient depth, but should profit immediately as a consequence of the improvements in the river. The traffic by steamboats had reached, before the opening of the railroads in 1887, 242 000 tons of freight between Lyons and Arles, with a considerable number of passengers. The steam fleet comprised 61 boats of a total of 24 000 H. P., among which were 5 grapnel towboats, and 18 boats more especially devoted to the transportation of passengers.

In 1857, immediately after the opening of the line from Lyons to Avignon, the passenger movement decreased considerably, and the freight transported fell to 160 000 tons. Half of the fleet remained at anchor; the traffic continued to decrease from year to year, and they continued to dismantle the boats.

In 1877, the year which preceded the law for improvement, the movement of freight was only 89 000 tons; there were only 10 boats in use, of which 6 were for freight only, 2 for passengers and freight, and 2 tugs. There was a gradual increase from this time; in 1880, it was 115 000 tons; in 1886, 130 000 tons, and in 1891, it had reached 161 000 tons. In 1891, the fleet included 20 steamers in regular service, comprising: 3 small towboats, upon cable, for local service; 4 boats for both freight and passengers, and 11 large boats for freight only.

It may be noted that the movement of freight by boats had returned in 1891 to the amount which it had reached in 1857, and with a much smaller fleet; that was due to the better utilization of the *materiel*, the length of the period of navigation being considerably extended. The number of trips of each boat has increased in the same ratio, while the tonnage carried per trip increased still more rapidly.

The average tonnage capacity of the boats now employed is 413 tons; the maximum tonnage per round trip is, then, 826 tons; in reality it is less, since, even when freight is plenty, the boats are less heavily loaded on the descent than on the ascent, for the purpose of limiting the enormous momentum which such masses acquire when they attain, as they do, at certain points, velocities of 22 to 24 km. per hour, and of making certain that the engine has sufficient power to overcome the velocity and stop the boat if occasion requires. With the improvement of the river, the straightening of the channel, which makes it possible to increase the distance between stops, and the reduction of the rapids, the difference between the loads for ascent and descent has very much diminished; the sum for ascent and descent is still considerably less than 826 tons, which is double the tonnage capacity.

In 1876, the tonnage was, at most, 450 tons; in 1880, it was 500 tons; 1885, 565 tons; 1887, 727 tons; 1889, 729 tons; 1891, 730 tons; that is to say, that for the last four years the degree of utilization appears to have practically attained its maximum.

The price of freight has naturally followed a downward path. Some comparative prices will permit of showing the reduction realized upon the goods which represent the greater part of the tonnage. The following table gives these figures:

Goods.	Route.	Price.		
		1876.	1884.	1892.
		Francs.	Francs.	Francs.
Metals	Lyons to Marseilles	12	11	9
Lime	Teil to Marseilles	11	7	6.50
Cereals	Marseilles to Dijon	26	22	17
Cereals	" Lyons	16	14	12.5
Vermicelli	" "	16	15	12.5
Wine	Cette and Marseilles to Lyons	17	16	14
Soap	Marseilles to Lyons	15	14	12
Sulphur	" "	14	13	11
Cordage	" "	22.5	16	12.5

There is, moreover, reason to hope that when the problem of traction upon the Rhône is solved, a problem of which a solution may be soon expected, the sacrifices made will not fail to bear fruit.

MARITIME NAVIGATION WORKS.

SECTION 1.—GENERAL STATEMENT.

France is bounded by the sea upon three of the sides of the hexagon in which it is inscribed. Its shores have, excluding islands, a total length of 2 710 km., viz., 1st, 1 223 km. from the northern frontier to Audierne (North Sea and the English Channel); 2d, 862 km. from Audierne to Bidassoa (Atlantic Ocean); 3d, 625 km. from Cape Cerberet to Pont Saint Louis (Mediterranean). The number of ports, harbors and anchorages along these 2 710 km. of shore line is several hundred, at 200 of which there are works of maintenance upon State lands.

The object here is not to give an enumeration of the maritime works of France, but to give a glance at the improvements realized in these works in the course of the period included between January 1st, 1876, and December 31st, 1891, embracing, consequently, 15 years.

Naval *materiel* within half a century has undergone a transformation which has directly affected the accommodations of the ports of commerce. The dimensions of ships have increased in considerable proportions ; the number of steamships has increased in a progressive ratio, while that of sailing vessels has notably diminished. Sail navigation has regained some favor at this time, it is true, but the new sailing vessels are generally of dimensions comparable with those of steamers ; they are equipped with mechanical appliances for loading and unloading freight, as well as for the handling of sails and anchors. The increase in the dimensions of ships permits of realizing important economies in the cost of transportation as much from the point of view of the working force as from that of the *materiel,* and particularly in fuel. Thus the tendency to increase the tonnage of ships is thoroughly justified, and the increase will continue.

The heavy expenses due to steam vessels force efforts to avoid loss of time and to derive the greatest possible profit from the output. The time spent by ships in port thus decreases from day to day ; in order to reach this result it is necessary to create a plant which will permit of rapidly loading and unloading freight, and to develop railroads and navigable water-ways, which will serve purposes of transportation.

In order to satisfy these new wants, the ports have been forced to undergo modifications which permit them to receive ships much larger than those which frequented them formerly, and to save the time formerly lost by them before or after loading.

The writer will first attempt to show the improvements of a technical character made in this connection in the course of the 16 years which we are considering ; then, after a rapid glance at the expenses contracted in the accomplishment of this work, he will proceed to show the economic results which have been reached in the development of traffic.

Section II.—Technical Explanation.

Chapter 1.—Conditions of Access to Ports.

The channels giving access to a large number of ports have been improved and deepened. Calais, Boulogne and Dieppe, especially, have been put in a condition to receive, at the wharves of their outer ports, at all stages of the tide, the vessels which carry passengers between France and England. This improvement which greatly facilitates communication between the two countries, has principally been secured and maintained by means of dredges. The bottom of the channel in these ports is kept at an elevation varying between — 2.50 m. and — 4 m.* The annual dredging required to maintain this condition is not excessive, for the volume does not exceed 300 000 cu. m. for Calais, 200 000 for Boulogne, and 110 000 for Dieppe. The accommodations of the tidal docks in these three ports have also been improved, principally at Calais, where the passenger service is performed under very comfortable conditions. The channel has also been deepened by means of dredges, 2.70 m. at Dunkirk, and 1.80 m. at Ouistreham, etc. Furthermore, the excavation of a passage has just been finished across the bar of the Charpentiers (off shore from the mouth of the Loire) which will increase the available depth 1.40 m. for ships in foreign commerce and destined for St. Nazaire. The depths at the entrance of the ports at Tréport, Cherbourg, Les Sables, Bayonne and Cette have been in like manner increased.

Suction dredges, which raise a mixture of water and of sand, and let the sand settle in pits with gates, which are afterwards emptied into

* In each port, elevations are referred to the zero of the hydrographic charts, this zero corresponding to the level of the lowest tide observed. The minus sign is given to elevations below zero.

the sea, have greatly contributed to these results by reducing the cost of dredging. At Dunkirk, Calais and Boulogne, the dredging done by the Administration has cost only from 0.17 to 0.29 francs per cubic meter. Upon the bank of the Charpentiers, the dredging has been let to a contractor at 0.80 franc per cubic meter; the price will be much less when the Administration des Ponts et Chaussées has in operation the suction dredge which has just been ordered.

At Dieppe, on the contrary, the nature of the bottom, which is composed of limestone and a mixture of sand and gravel, requires the use of bucket dredges; and the cost amounts to 0.92 franc per cubic meter. This price is greater than that which they expect to pay at Havre with a dredge of greater power (its engine being of 500 H. P.) which has just been put in use.

Independently of dredging, other works have been undertaken at different points to improve the conditions of entrance into ports. At the entrance to Boulogne, the roadstead has been sheltered by the "Carnot" break-water founded in a depth of 8 m., and with a length of 2 110 m. Some dredging has been done for the purpose of increasing the sheltered surface where large ships can anchor. The entrance of the port of Cette has also been rendered safer by the extension of the break-water 850 m. to the east.

The inner channels of the ports of Dunkirk, Calais, Tréport, Dieppe, St. Valéry, Fécamp and Havre have been enlarged and at the same time straightened by the building of one and in some cases two jetties; they have also been deepened. These works greatly facilitate the movement of ships; furthermore, there is less danger of a ship's stranding, completely barring the channel, and entirely preventing egress or ingress, as had previously happened in certain cases.

The depths which have been attained in these different ports are, moreover, not considered as limits which will not be surpassed. On the contrary, an increase in depth of water is now anticipated, notably in the channels of approach to the ports of Dunkirk and Havre, and the time is approaching when the exterior passage and the channel included between the jetties in these ports will be excavated to from 4.50 to 5 m. below the lowest tides. The legislative difficulties which have so far retarded the execution of this programme seem about to disappear, so far as Havre is concerned.

As a result of the studies made by the Hydrographic Service of the

Navy for the purpose of discovering the proper means of rendering the port of La Rochelle accessible to the largest ships, the idea of improving the present port has been given up, and it has been decided to construct a new maritime establishment at La Pallice. This port, now opened to navigation, opens upon a roadstead of the first order, perfectly protected in every part. The outer port is excavated to the elevation — 5 m., so that the depth of water at high tide is between 9.65 and 11.55 m., and at low tide between 5 and 6.95 m. The depth in the basin is not more than 1 m. less than that in the outer port. The cost of establishing this new port has been but slightly increased by the rocky nature of the bottom, which is solid enough for foundations, and not solid enough to make the excavation very costly. The west coast of France has thus been provided with a safe and deep port; its absence had been regretted, and might have become serious under certain circumstances.

Flushing, which has for a long time been one of the principal means of maintaining the depth in channels, can no longer render real service under the new conditions; it has been almost wholly abandoned, notably at Dunkirk where the system was very fully developed, and has been replaced with advantage by dredging. But at Honfleur, with the special conditions of filling up which threatened this port, flushing has not only been maintained, but has been further developed, a new flushing basin having been built. Very ingenious and interesting arrangements have been adopted, in order to fill this basin at will exclusively with sea water during high tide, in order to prevent as much as possible the entrance of muddy water. The supply weir established for this purpose works excellently.

Chapter 2.—Interior Arrangements of Ports.

The interior arrangements of the ports have also undergone great modifications. The old works have generally been retained, but new ones have been constructed to receive large vessels, and satisfy the increase in traffic.

Nearly all the ports have been supplied either with new wet docks, or with deep-water quays. Wet docks have been constructed at Dunkirk, Calais, Dieppe, St. Valéry-en-Caux, Fécamp, Havre, Honfleur, Granville, St. Malo and St. Servan, Le Légue, St. Brieuc, Paimpol, St. Nazaire and Rochefort.

Tidal quays and open docks have been constructed at Boulogne, Tréport, Rouen, Caen, Calais, Lorient, Nantes, Les Sables-d'Olonne, and Bordeaux. The ports of the Mediterranean and of Algeria have also received noticeable improvements. Important works have been executed at Marseilles, Cette, Nice, Bastia, Ajaccio, Alger, Oran, Bone and Phillippeville.

Locks larger and deeper than those which have previously existed have been established in certain cases, in order to give ships sufficient access to basins. This has been the case notably at Cherbourg, Trouville, etc. The dimensions of the locks and the depths of basins and docks have been varied according to the types of ships which frequent the different ports. The width of the locks thus constructed has not been less than 30 m. at Havre, 25 m. at St. Nazaire and Dunkirk, 22 m. at La Pallice and 21 m. at Calais and Dunkirk. The most of them are provided with a chamber of large dimensions: 172 and 117 m. at Dunkirk; 167.50 m. at La Pallice; 150 m. at St. Nazaire, 133.50 m. at Calais; 100 m. at Fécamp.

The elevations of the lift wall are — 5 m. at Dunkirk; — 4 m. at La Pallice; — 1.75 m. at St. Nazaire and Calais, etc. The heights of the quay walls recently constructed have often been considerable, especially in the outer ports, where, at the same time, depressions have been excavated in which ships remain afloat at low tide. This arrangement has been adopted at Calais, Boulogne and Dieppe, as well as other places, for the packets in the service with England, and it is also found in the project adapted for Havre. The quay of the outer port of Calais is founded for part of its length at the elevation — 10 m., which gives it a total height of 19 m.

The construction of new works is often effected under particularly delicate conditions, on account of the nature of the bottom. The basin of Penhouet, at St. Nazaire, the third wet dock at Rochefort, and the quays of Bordeaux especially, have been founded in mud of great depth. Recourse has been had to the use of masonry wells, sunk by excavation through the shaft, as had previously been done at Havre and at the wet dock of Bordeaux. The inclination of the rock upon which the wells rested at St. Nazaire required its blasting into steps and the construction of masonry beneath the wells, which has considerably increased the difficulties of this work.

At Rochefort, the inflow of material beneath the wells has very

much hindered the foundation work. Under certain circumstances this sinking could be accomplished only by the use of compressed air. The shaft in the interior of the mass is in this case filled to a certain height with masonry save in the central portion, where a pipe is placed surmounted with an air chamber, serving for the extraction of the earth and the entrance of materials. The lower part of the shaft preserves its full dimensions and serves as a working chamber. Under these conditions, there is left remaining in the masonry only 350 kg. of iron per block. The excavation for the blocks was made by a water-jet, the earth, particularly at Calais, being composed of homogeneous sandy material.

The masonry blocks have often large dimensions in plan: 8 x 8 m. at Calais, and 10 x 6.70 m. at Havre. At Bordeaux, some blocks have been sunk 32 m. long by 6 m. wide. The descent is made very regularly by taking proper care, and blocks which have become inclined for any reason can be straightened up without difficulty. This mode of construction has even been employed with great success in works executed at points on the shore directly exposed to the sea. The jetties of Trouville and of Calais and part of the quays of the west dock of the Bellot basin were founded under these conditions.

Water-jets have also been employed on a large scale for sinking stone, and also wooden sheet piles, especially at Calais, Honfleur and Dunkirk. This method is very rapid and economical. At Calais the sinking of a section of sheet piling 1.80 m. to a depth of 2.50 m. was effected on an average in 1 hour and 10 minutes, while the driving with a hammer required 8 hours 30 minutes. The thickness of the sheet piling, moreover, could be reduced from 0.12 to 0.08 m.

Compressed air has been employed to a considerable extent in the execution of the works, because of the facilities which it offers and its relatively economical cost in permeable soils full of water. The jetties of Dunkirk were founded by this method, as well as the quay walls of Dunkirk, Calais, Boulogne, Fécamp and Bordeaux.

In the construction of the water barricades, iron is substituted in part for wood, which previously was alone employed; but the latter is still used almost exclusively in the construction of frame quays. Among the recent metallic barricades we may note those of Havre, Dieppe, Fécamp and St. Valéry-en-Caux. Metallic structures present important advantages as to strength and durability.

The gates of the locks are now constructed almost exclusively of iron. It is becoming more and more difficult to find timber which will give the rectangular cross section of the size required for gates of large dimensions. Iron gates are more rigid; the joints do not constitute the weak points as in wooden structures; the plating of iron gives to the structure a stiffness and invariability of form which cannot be obtained with wooden gates, in spite of the use of brackets, straps and bands. Moreover, metallic gates, by the use of air chambers conveniently placed and of sufficient dimensions, can bear at pleasure much or little upon the lower pivot, and the load remains practically constant, whatever may be the height of water at which the operations of opening and closing take place. They last much longer than timber work, and cost much less for locks of large dimensions. The reduction of cost was not less than 25% for the gates of the west lock of the Freycinet basins at Dunkirk, and 30% for the gates of the locks for transatlantic ships at Havre.

At Dunkirk, Havre, and several other places, a few gates are made up of vertical members bearing against an upper and a lower girder, instead of using a series of horizontal members. In this system, which is economical when the height approaches or is less than the length, the pressure is distributed very favorably. The sill supports the larger part of the load and the dimensions of the vertical members can be calculated exactly; on the contrary, in the system of multiple girders, one is obliged to make hypotheses, and to make up for the uncertainty of the methods of calculation, it is necessary to sensibly increase the dimensions in order to leave no doubt as to strength. Horizontal multiple girders, which are necessarily near together, render moving around and inspection in the interior compartments more difficult than vertical members; the latter divide the gate into passages in which one can move about easily.

The substitution of a single-leaf gate has, in some cases, been advocated for the double miter gates, which, up to a very recent time, were exclusively used for closing locks, in order to reduce the dimensions of the framework. The single leaf is easier to operate and does not present the same causes for wear and destruction as the double miter gates. These latter should be exactly of the same length as the miter-sill; they should, moreover, be always closed together and well placed relatively to each other, conditions which it is difficult to ful-

fill, especially in operating the gates of a lock in service, or when the sea is rolling.

The single leaf, on the contrary, always bears well upon the frame and sill, and it is easy to prevent the single leaf from striking by holding the free post by means of a bolt or hook. On the contrary, the use of gate hooks or springs only imperfectly prevents the striking of gates mitered against one another, and the deterioration which these repeated blows produce. Gates with a single leaf have been adopted for the locks of Tancarville and Fécamp, which are 16 and 18 m. in width of opening. It cannot be doubted that this system will become more general, having given the excellent results mentioned in these two cases.

The breakwaters and quays built in the Mediterranean have been constructed in enrockment of natural or artificial blocks, the handling of which has been facilitated by a special machine permitting the use of blocks of large dimensions.

Chapter 3.—Docking Apparatus.

In 1876, Marseilles, Havre, and Bordeaux were the only ports in France in which there were dry docks. In the other ports, the means of repair consisted almost exclusively of ways and pontoons for careening; wooden floating docks had, however, been established at Havre and Marseilles. Since that date dry docks have been constructed at Dunkirk, Calais, Dieppe, Havre, Cherbourg, Paimpol, St. Nazaire, La Pallice, Bayonne and Marseilles. Repairing slips have been built at Dunkirk, Bordeaux and Rouen.

Dry docks render the greatest service to navigation, and especially to iron ships, whose bottoms require frequent repainting. The docks at Dunkirk, Marseilles, La Pallice and Havre can receive the largest ships; they have lengths between 170 and 200 m. Their construction, which was relatively easy at St. Nazaire, La Pallice and Marseilles, where the material is rock, has presented great difficulties in other ports, an account of the nature of the earth and the abundance of springs. In order to put in foundations one has been forced to employ either masonry wells sunk by excavating through the shaft, as at Bordeaux, or caissons with compressed air, as at Bayonne. The walls usually have only a small number of offsets. The blocks, the height of which varies from 0.90 to 1.10 m., are metallic in the most recently constructed docks.

Pontoon gates have been preferred to abutting gates for closing the entrances to dry docks, as being tighter and occupying less length. The increase of time required to operate them, and the necessity of having a relatively large force of men, does not constitute a serious inconvenience, having given plenty of time, and the number of workmen necessary for these operations as well as for blocking up.

The apparatus for emptying is generally composed of two separate parts, one consisting of centrifugal pumps of large dimensions, designed for emptying the basin, the other consisting of centrifugal pumps or piston pumps indifferently, used for keeping it empty. The large docks of Dunkirk and of La Pallice, which contain 44 000 cu. m. of water each, can be emptied in three and a half hours, and those of Calais and Havre, which contain 32 000 cu. m., in three hours. Generally the steam engines operate the pumps directly; nevertheless, belts are used at Calais and St. Nazaire. The installation has been made so that the service may be assured in case of cleaning or repair of a boiler or engine.

Chapter 4.—Improvement of Maritime Rivers.

Considerable work has been undertaken on the Seine, the Loire and the Garonne, in order to facilitate the access of ships to the ports of Rouen, Nantes, and Bordeaux. On the Seine, the jetties commenced in 1848 have not been extended above Berville; but in the river, the banks have been straightened and important dredging has been done, notably across the bar of Meules, at Bardonville, the Ile-aux-Oiseaux, and Croisset. Independently of the recovery of over 20 000 hectares drained of water, the improvement of the Seine has given very satisfactory results to navigation.

Rouen formerly received boats of only 100 to 200 tons burden, having at most a draft of 3 to 3.50 m., and reaching there in about four days; to-day, boats having a draft of 5.50 m. arrive at its quays regularly at neap tide, and those of 7 m. at spring tide. The tonnage of ships entering, which was only 263 210 in 1861, and 418 100 in 1876, reached 1 211 435 tons in 1891. Ships now regularly ascend to Rouen on a single tide, but the descent requires two. The crossing of the estuary, which until recently could only be done by day, can now be done also by night, on account of the buoying of the channel with lighted buoys.

On account of the results obtained, the work of prolonging the dikes in the estuary is now progressing. The southern dike should be continued to Honfleur, the northern dike should stop about 3 km. above. This work and the removal of several shoals situated above in the river will result in an increase in the depth of water of almost 1 m. A law will be presented to the Chamber of Deputies for the purpose of authorizing the execution of this project.

Since boats for interior navigation cannot venture into the mouth of the Seine without risk of serious danger, a canal has been opened between Tancarville and Havre, in order to give them access to this port. This canal, which is 25 km. long, has a depth of 3.50 m. for the greater part of its length, and 6 m. as far as Havre. The structures are so built that this depth can be extended throughout the whole length. Locks with 16 m. openings and chambers 180 m. long and 30 m. wide, are placed at each extremity of the canal. Since the opening of this water-way inland boats arrive easily at Havre, without having anything to fear from the bar.

The Loire has been improved in such a manner as to allow access to the port of Nantes by ships drawing 5.50 m. The régimen of the river has been improved above by means of longitudinal dikes, and deepened above and below by means of dredging. But the depth of the intermediate portion included between the Carnet and the Martinière, in which are found numerous shallow places, apparently cannot be increased beyond 4.50 m., at least without excessive expense. It has therefore been decided to open a lateral canal, 15 km. long, to the right of this section; this canal is terminated at each end by locks of 18 m. opening, with chambers 100 m. long by 40 m. broad. The breadth of the basin is 24 m. at the bottom. It has been open to navigation since September, 1892, but the deepening of the Loire will not be finished until next year.

The improvement of the upper Gironde and of the maritime Garonne, from Pauillac to Bordeaux, which was begun a long time ago, has received a new impulse since the passage of the law of August 3, 1881, appropriating a sum of 30 000 000 francs for the execution of the works. The pass of the point of Ambés, which was one of the greatest obstacles to navigation, has been deepened, as has also the bar of Beychevelle; the Cazeau Isle and the Isle of the North have been removed, and the point separating the Garonne from the Dordogne has been reinforced

for 600 m. of its length. The depth of water on the pass above, which at low tide was only 0.90 m. in 1869, and 1.55 m. in 1888, is now more than 4 m. Upon the shoal of Beychevelle the dredgings have shown a ledge of soft rock, which reaches at some points to within 3.25 m. of low water-mark. A channel 100 m. wide presenting at least this depth is now open; it should be deepened to at least 4.50 m. or perhaps even to 5 m. below the level of ebb tide.

Dredging has been equally effective upon the bars of Carriette and of Bassens. The straightening of banks and dredging have been done with the object of unifying the direction of the flood and ebb currents in the channel of Bacalan. The depth of this passage below ebb tide which was only 2.50 m. in 1860, will soon be increased to 3.50 m. The improvement of the banks has also permitted giving Bordeaux a great length of wharf and of inclined slips for the loading and unloading of freight. The works have been carried on with a view to putting the passes of the Garonne into a condition to offer to large ships a safe and easy passage to the port of Bordeaux at all stages of the tide.

The jetties at the mouth of the Adour have been prolonged a little since 1876; there has resulted from it a new lowering of the bar, which is now 3.10 m. below the level of ebb tide. The jetties clearly seem now to have done all that one can attain by their use, and attention is being given to increasing the depths by dredging.

Chapter 5.—Wharf Equipment.

The Administration des Ponts et Chaussées attends only to the construction and maintenance of harbor works, their approaches and dependencies; it generally does not interfere with the location of railroads which are built by the railroad companies, nor with the public plant, properly speaking, shelters, store-houses, tools, etc., which are usually put up and operated by Chambers of Commerce, and sometimes by contractors. A certain number of navigation companies also possess plants which they use for their own particular needs.

The public plant amounted to almost nothing in 1876; it included only an occasional machine for loading and unloading, and some dock warehouses, of which only one, that of Marseilles, was conveniently provided with mechanical appliances for handling freight. Since this period great progress has been made. Special attention has been paid to improving the systems of navigable water-ways and that of the rail-

roads, and to putting them in direct communication with the basins and wharves of the maritime ports. Freight now arrives and departs much more rapidly and at less expense than formerly. The radius of action or of influence and the population served by ports have very much increased..

Tracks are built upon the quays in nearly all the ports, even those of the second order; they are placed according to circumstances, in such a manner as to permit either a direct transfer of freight from ships to car or conversely, or loading after inspection and delay upon the quay ; or storage upon the quay before the arrival of the ship. In certain cases, the tracks are also used to facilitate the transfer of goods to storehouses after unloading from the ship.

Cranes and other hoisting apparatus have been put up in a number of ports, according to the importance and nature of the traffic. These machines are operated by hand, by steam or by hydraulic pressure; the use of electricity has been studied, but it has not yet been put in practice. Hydraulic pressure has been adopted, notably at Dunkirk, Calais, Havre, Rouen and Marseilles.

Sometimes cranes, instead of being placed on shore, are put on pontoons. This system, which presents certain advantages, has received its principal application at Rouen. Cranes of this nature are used at Havre, at Dunkirk and at Honfleur.

Quays provided with rails and with cranes have been used for the direct trans-shipment of coal and minerals at Dunkirk, Dieppe, Fécamp, Rouen, Le Havre, St. Nazaire and Bordeaux. Other quays have been arranged with reference to special traffic; but in most cases the quays have been arranged so as to satisfy in a general way the various needs of commerce. Tracks to the number of one, two or three are then placed along the quay walls, for use in direct trans-shipment between ships and cars; another system of two or three tracks is placed for a certain length along the road at the other edge of the quay embankment or platform. The large surface left between these two systems is used for storage and examination of freight which may be received and weighed. This surface is sometimes covered, particularly when the quay is used for the handling of valuable products such as wool, cotton, sugar, leather, etc.

The ports which are thus provided with sheds are daily increasing in number. Independently of large ports like Dunkirk, Calais, Havre,

Rouen, St. Nazaire, Bordeaux and Marseilles, there are also storehouses and shelters at Tréport, Dieppe, Caen, Les Sables, La Pallice, etc.

Aside from cranes of small power (from 1 250 to 1 500 kg.) serving for the loading and unloading of ordinary freight, there have been placed in the principal ports shears and engines for masting able to raise very heavy weights. There may be cited, among others, the shears at Marseilles, 120 tons; at Havre, 100 tons; at Nantes, 60 tons; at Bordeaux, 50 tons; at Dunkirk, 40 tons; and at Havre, Rouen and Dieppe, 30 tons. The most of these machines are fixed on shore; but some of them are floating, as the 40-ton crane at Dunkirk and the 80-ton at Havre.

Chambers of Commerce cover the cost of construction, maintenance and operation of the loading apparatus and buildings by means of taxes paid by those who use them, and in some cases by means of a tonnage tax, collected from all ships entering the port. This last system, which is resorted to when the direct tax is insufficient, exists at Dunkirk, Calais, Bologne, Dieppe, Rouen, Honfleur, Caen and Bayonne.

Chapter 6.—Lighthouses, Beacons and Sound Signals.

Within a few years some new lighthouses have been constructed, among which we may note the masonry lighthouses of Vieille (Finistère), of the great Cardinaux (Morbihan), of the great Charpentier (lower Loire), and Antifer (lower Seine). The first three are situated upon isolated rocks in the sea. A lighthouse built upon a metallic column on the pier head of Port Vendres is interesting on account of its peculiar construction.

Important improvements have been introduced in the apparatus, notably by the adoption of the super-radiant and flashlight systems. The super-radiant apparatus, or one of long focus, is 2.66 m. in diameter, and permits of increasing the light three-fold, that is to say, to the power of an apparatus of the first order. A light of this system has just been installed at Antifer.

The flashlights are characterized by flashes occurring at short intervals, and of short duration. Experience shows that there is no gain by prolonging the duration of the flash from a lighthouse beyond the minimum time necessary for the perception of the full inten-

sity, and further that there is a loss of light proportional to the excess of time. The maximum efficiency compatible with an optical apparatus of a given order is that obtained by flashing every 5 seconds, limiting the flash to the minimum time of complete perception, estimated at $\frac{1}{10}$ second, and in carrying the intensity of the emitted beams to a maximum. This last consideration requires the use of a single lens embracing a semi-circumference in plan, and, therefore, concentrating in a single beam half of the light emitted by the lamp. With a reflector having an efficiency which may be estimated at one-third, the other half of the light can be used in this system, and thus realize 0.83 of the total light. This combination realizes an efficiency which has never before been attained with flashing lights; but on account of the velocity of rotation which it requires (one turn in five seconds), it is necessary to give to the beam a large horizontal divergence. This requirement limits the employment of systems with a single lens to the fifth, fourth and third orders, if the dimensions of the six-wick burner, beyond which mineral oil lamps cease to be practical, cannot be exceeded. With two lenses, each embracing a semi-circumference, half of the total light is utilized, and the type can be applied to all orders.

The new system does not require the use of apparatus with four lenses, except for electric lights, in which the dimensions of the light are very small. Among the apparatus constructed on this principle there may be noted one of the fifth order with a diameter of 0.375 m. established at the lighthouse in the sea at La Teignouse, and a system of four lenses, having a focal length of 0.3 m., designed for the electric light north of La Hève. The intensity of the beam emitted by these lights is about 20 000 C. P. for the first, and 2 300 000 C. P. for the second.

Flashlights have necessitated the invention of a new mechanical combination in order to assure, by simple clockwork, the rapid rotation of the heaviest optical apparatus. This arrangement consists in carrying the optical part upon a floating ring resting in a dish of mercury of the same form. The pressure of the liquid is calculated to counterbalance the weight of the apparatus.

The most important lighthouses situated near great shoals, to the number of 13, will all be lighted by means of electricity. The transformation has already been made for 10 of them. Numerous

improvements have been introduced in the installation of the last electric lighthouses; optical apparatus permitting of an increase in the horizontal angle included by the lenses; an improvement of the rotating machine and its accessories; the employment of hot-air motors; modifications in the disposition of the machines and electrical regulators, as also the establishment of instruments of control. All these improvements, especially the organization of flashlights, have been designed and executed under the direction of M. Bernard, Inspector-General, by M. Bourdelles, the Chief Engineer of the Central Lighthouse Service.

The last electric lighthouses constructed, except that of La Hève, have been supplied with siren foghorns capable of instant operation by compressed air.

Permanent lights have been established at various points. After having tried gasoline at the turret of Lavardin, the use of ordinary mineral oil is now preferred. The results are satisfactory, and it is certain that the light will continue to burn, in good condition, without attendance, more than two months. A certain number of lights of this nature have been established, notably at Palais (Belle Isle), La Corne, St. Waast, the turret of the Morées (St. Nazaire), etc. This system seems appropriate for use in the lighting of jetties which are inaccessible for a long time, beacon towers, and points of secondary importance, which will not bear the expense of establishing and maintaining ordinary lighthouses.

Two lightships have been rebuilt on new designs, to replace those which were anchored near Dyck and Ruytingen, off the coast of Dunkirk. The stability of the ships has been determined in such a manner that the pendulum-like oscillations of rolling and pitching, in calm water, permit of no synchronism of their movement with that of the waves. The time of the rolling has been doubled, and its amplitude has been reduced one-half. The lights have been elevated, and the optical apparatus placed in a lantern sufficiently large to permit of the keeper looking after it without its being necessary to lower it upon the bridge as formerly. This apparatus has lights with a power which attains 1 200 C. P., while they did not exceed 48 C. P. in the old floating lights.

The floating light Ruytingen is supplied with a siren, working by compressed air.

The considerable cost which was occasioned by the establishment of floating lights, and especially the large expense required for their maintenance, has acted to restrain the use of these costly machines, and to replace them, as far as possible, by luminous buoys. These buoys necessitate relatively very small expense, and their number can consequently be multiplied, in order to reduce danger, or to indicate a route to be followed, more efficaciously and more economically than by the aid of lightships.

The buoys of the type called "a queue" are provided with lenses 0.20 to 0.30 m. in diameter, placed in the lanterns. The consumption per hour is from 20 to 30 liters of coal-gas, compressed to six atmospheres in the body of the buoy. The applications of this system of lighting become more numerous every day. Luminous buoys have been established at Minquiers, upon the shoal of Vergoyer, on the roadstead of Dunkirk, and to mark the channel of the Seine. Others will be placed in the Gironde and at the entrance of the Loire.

The number of luminous buoys in use on the coast of France is now 61 ; it will be nearly 100 at the end of the year 1893. The rapid development shown is the best demonstration of the value of this new method of lighting.

Section III.—Expenses and Traffic.

Chapter 1.—Expenses.

The maritime ports of France belong exclusively to the State. They have been constructed from the resources of its budget, and also in certain cases from local contributions, furnished by departments, cities, or chambers of commerce. The maintenance is wholly at the expense of the State.

	Francs.
The first cost of construction of maritime ports, from the 17th century to 1814, may be estimated at about	130 000 000
From 1814 to 1876 the cost reached	442 000 000
Total cost before 1876	572 000 000

The mean annual first cost of construction for the 52 years between 1824 and 1876 was only about 8 000 000 francs. Beginning with 1876, the annual expenses increased rapidly ; they exceeded 20 000 000

francs in 1877; they reached 52 000 000 francs in 1883, and have decreased since.

	Francs.
From 1876 to 1891, inclusive, there has been spent for the improvement of maritime ports a total of	522 600 000
The annual average for this period of sixteen years is thus	32 000 000

The greater part of these expenses has been taken from the national budget, supplied by the general tax. The users of a large number of ports have, however, been called upon to contribute to the expenses by means of special tonnage taxes, collected at the entrance of the ports. Parliament has a marked tendency to apply this system more and more. These local taxes are generally collected in each port, at the custom-house, for the benefit of the city or chamber of commerce, which is commissioned to furnish grants to the State for the execution of the works, the division having been fixed by the laws authorizing the works. The necessary funds for the grants are borrowed by the cities or chambers of commerce, and the lenders are reimbursed, both principal and interest, by means of taxes. The taxes cease to be collected when the reimbursement is completed. The amount of the subsidies thus furnished from 1876 to December 31st, 1891, was almost 80 000 000 francs. The amount of local taxes during the same period rose to nearly 56 000 000 francs.

For the division of the expenses and grants which we have just indicated in round numbers, by ports and groups of ports, the reader is referred to a table at the end of this paper, in which the conditions of the ports are presented for the years from 1876 to 1891, as to expense as well as to technical conditions of establishment and the movement of ships and traffic.*

We may especially mention here the subdivision of the expenses contracted from 1876 to 1891, by groups of ports, divided for the purpose into three classes. The traffic for 1891 has been taken as the basis for the classification. There is ranged, in the first class, commercial ports in which the traffic in 1891 exceeded 800 000 tonnage capacity (ships entering and departing); in the second class, commercial ports in which the traffic was between 80 000 and 800 000 tonnage

* In this connection, see annexed Table No. 1.

capacity; in the third class, the small commercial ports and fishing stations, of which the traffic was less than 80 000 tonnage capacity.

The expenses are divided in the following manner:

	Francs.	Percent.
10 ports of 1st order........	354 217 000	67.7
28 ports of 2d order.........	131 534 000	25.2
172 ports of 3d order.........	36 855 000	7.1
210 ports. Total............	522 606 000	100

On collecting the figures for the tonnage capacity of loaded ships and those in ballast also, it will be found that this tonnage will be divided in the following manner between the same groups of ports:

	Tonnage Capacity.	Percent.
Ports of 1st order.............	33 438 000	76.3
Ports of 2d order.............	7 898 000	18.0
Ports of 3d order.............	2 500 000	5.7
Total	43 836 000	100

If we take account of the fact that the great ports have to serve multiple interests outside of the commercial traffic, such as that of passenger and mail service, and that the small ports constitute, also, a refuge for the innumerable fleets of fishing-boats of which the tonnage does not figure in the numbers given above, we will find that the expenses of first establishment are divided very exactly in proportion to the commercial importance of the port.

Chapter 2.—Movements and Traffic.

We shall distinguish in our statistics:

First.—Navigation along the coast between French ports.

Second.—Navigation from French ports to foreign, and conversely.

The coasting trade between French ports was represented in 1875 by a tonnage capacity of 7 950 000 tons (both arrivals and departures). This tonnage had increased in 1891 to 12 233 000 tons, and is a very noticeable increase.

The movement of navigation between French ports and foreign ports was measured by a total tonnage capacity (arrivals and departures of loaded ships and ships in ballast) of 16 717 000 tons in 1875,

and 31 603 000 tons in 1891. The total has increased, in round numbers, from 24 600 000 to nearly 44 000 000 tons.

The importance of foreign maritime commerce depends on the importance of the general commerce outside of the country. It will then be useful to give a glance at different periods to general commerce outside of France. A table will be found in the appendices to this memoir in which the movements of foreign commerce are brought together for the following dates: 1827, 1847, 1859, 1875, 1891, and where the figures are given relative to the movement of values, weights (at least since 1859), tonnage, separated into internal movements and maritime movements, importations and exportations, national flags and foreign.*

We will not here analyze this table previous to 1875. We note that in value as in weight, the maritime movement is always greater than the inland movement, and that it is undergoing a rapid extension. In 1875, the maritime movement, leaving out that of passengers and mail service, amounts to 11 320 000 tons of freight, valued at 6 101 million francs.

In 1891 these figures had reached respectively 20 894 million tons for freight, and 7 504 million francs for value.

Such figures suffice to justify the considerable expenses which France has contracted for the improvement of her maritime ports. But this analysis may be carried farther. The 11 320 000 tons of freight of foreign commerce were transported, in 1875, by ships of a total tonnage (both arrivals and departures) of 13 470 000 tonnage capacity (tonnage of loaded ships). If, to give the total movement, we add the ships in ballast, the tonnage is increased to 16 717 000 tons. In 1891, when the weight of freight had increased to 20 894 000 tons, the tonnage of ships loaded had increased to 25 136 000 tons, that of ships loaded and in ballast to 31 603 000 tons.

The substitution of steam vessels for sailing vessels has notably increased; as early as 1875, steamships represented a tonnage of 10 350 000 tons out of a total of 16 717 000 tons, or 62 per cent. In 1891, out of a total tonnage of 31 600 000 tons, steamships included 27 506 000 tons, or 87 per cent.

Not only do steam vessels include the total increase, but they have partially replaced sailing vessels. The preponderance of the use of

* See the annexed Table No. 2.

steam is also manifest in various ways according to the kind of navigation which is considered. Confining ourselves to European seas and to the basin of the Mediterranean, with a tonnage of 22 318 000 tons in 1891, steam navigation comprised 19 732 000 tons, or 88 per cent.

For long distances (commerce with French colonies not included), in a tonnage movement of 5 724 000 tons, steam navigation includes only 4 568 000 tons, or 79 per cent. In the commerce with Algiers and Tunis, the total tonnage is 2 900 000 tons; steam takes 2 852 000 tons—sail navigation is absolutely annihilated. In the commerce with the other French colonies steam navigation plays a role of much less importance, since in a tonnage of 530 000 tons, it takes only 358 000 tons.

It would no doubt be interesting to follow this analysis of the movement of our maritime commerce, but we will refer to a series of tables which can be found in the appendices at the end of this memoir.*

What has been said is sufficient to bring out a new characteristic of maritime navigation. The remarkable development of steam navigation coincides with the tendency to the concentration of maritime navigation in the hands of a few great companies. These lines themselves tend to substitute navigation in a circuit for direct navigation between two ports. A certain ship sailing at a fixed date completes its loading for a certain number of ports included within a certain radius. Upon its route and at its destination it takes on and discharges freight, and thus attains a reasonable utilization of a capacity enlarged for the purpose of reducing the general expenses per ton capacity.

In France, this tendency has been increased by the concession to a few companies of the monopoly of postal transportation, and of privileges in what relates to the transportation of passengers and ocean expressage. The annual subsidies given to these companies by the State now exceed 25 000 000 francs. Premiums for navigation by long voyages have also contributed to the development of regular lines of freight boats between France and North and South America, and the countries of the extreme east.

At the same time that regular lines and circuit navigation developed, it is rational to suppose that the capacity of ships would increase. This can be seen from the following table where, formed for showing

* See annexed Tables Nos. 3 and 4.

the increase in our exports, which divides ships by the kind of navigation. The comparison for the years 1875 and 1891 is for sailing vessels and steam vessel:

Kind of Navigation.	Average Capacity.			
	In 1875.		In 1891.	
	Sail.	Steam.	Sail.	Steam.
	Tonnage.	Tonnage.	Tonnage.	Tonnage.
European Seas, except Algeria............	121	333	195	515
Algeria..................................	160	525	160	713
Seas outside of Europe, except the Colonies	432	1 671	696	1 987
Colonies.................................	318	644	385	1 500

We see that the increase of average capacity is considerable. This increase is especially remarkable for steamships, and particularly for the navigation of seas outside of Europe.

In order to complete the account of the transformation which maritime navigation has undergone, the effect of which has reacted upon our ports and has necessitated the important works considered above we believe that it will be equally interesting to note the modifications which have been effected in the French ships attached to our ports. These modifications moreover confirm the observations made at the time on the movements of ships, in arrival and departure.

Coasting Trade Between French Ports.—In 1875, the number of sailing vessels employed in the coasting trade was 2 460, the total tonnage capacity being 96 927 tons; the average tonnage was 39 tons. The number of steam vessels engaged in the same service was 144, with a total tonnage capacity of 12 859 tons and the average tonnage was 89 tons. In 1891, the number of sailing vessels had decreased to 1725, with a tonnage capacity of 86 319 tons and an average tonnage of 50 tons. The number of steam vessels had increased to 145, with a total tonnage capacity of 13 773 tons, an increase of one vessel and 914 tons. The average tonnage had increased to 95 tons.

Navigation of the European Seas and of the Mediterranean.—In 1875, the number of French sailing vessels was 893, with a tonnage capacity of 45 197 tons, and an average tonnage of 51 tons. The number of French steamers was 152, with a total tonnage capacity of 78 476 tons and an average of 516 tons. In 1891, the number of sailing vessels had

decreased to 280, with a tonnage capacity of 53 526 tons and an average of 191 tons. The number of steam vessels has increased to 290 and the tonnage capacity to 165 985 tons, gaining 98 ships and 87 509 tonnage. The average capacity has increased from 191 to 664 tons.

Navigation of Seas Outside of Europe.—In 1875 the number of French sailing vessels was 1 084, with a tonnage capacity of 338 261 tons, and an average tonnage of 312 tons. The number of French steamships was 78, with a tonnage capacity of 97 865 tons and an average of 1 255 tons.

In 1891, the number of sailing vessels had decreased to 324 with a tonnage capacity of 136 574 tons and an average of 421 tons, an appreciable increase over the average of 1875. The number of steamships had increased to 187 and the tonnage capacity to 319 279 tons, gaining 109 ships and a tonnage of 217 414 tons.

At the same time with the average capacity, the dimensions of ships in length, in breadth and in depth, have undergone a considerable increase. The averages it will not be worth while to give here, but if reference is made to the data upon steamships published by the Bureau Véritas, it may be noted among the fleets of the transatlantic companies ships with dimensions exceeding 160 m. and even 188 m. in length, 20 m. in breadth and 9.50 m. draft.

In view of the necessity of serving a constantly increasing traffic under the conditions indicated above, and of permitting the entrance of ships whose dimensions are continually increasing, it is evident how urgent is the necessity of adapting our ports to these new requirements.

By referring to the annexed Table No. 1, it will be seen that the depths at the entrance and in the channels of our principal ports have been sensibly increased. The useful lengths of the quays, which in 1876 amounted to 139 732 m., have increased to 194 428 m. These figures are destined to increase rapidly. The proportional increase is, moreover, much more considerable than the absolute figures seem to indicate, for it has taken place almost exclusively in ports of the first order, where the lengths are doubled. Moreover, the equipment works have had the effect of increasing the use and efficiency of the port.

CONTENTS.

CONTENTS—(*Continued*).

NOTE.—Figures like this { 7.20 / 7.40 / 7.40 } correspond to { 1876. / 1891. / contemplated.

Direction of Roads, of Navigation and of Mines.—Conditions

Designation of the ports (arranged in order of importance).	Total tonnage capacity (inbound and outbound).	Goods, traffic (in tons of 1 000 kg.).	Total quantity of fish received (in tons of 1 000 kg.).	Minimum depth of water at entrance and in the channel.			Length of	
				At high water of mean spring tide.	At high water of minimum neap tide.	At low water of minimum spring tide.	Full depth of water.	Sh wa
1	2	3	4	5	6	7	8	
1 Havre...........	3 699 233 5 945 923	2 081 894 3 383 059	189 106 (a)	9.85 9.85 (b) 12.35	7.90 7.90 (b) 10.40	2.30 2.30 (b) 4.80	8 000 11 565 (b) 12 065	6 1 (2
2 Bordeaux........	2 352 934 3 527 210	1 866 300 2 582 471	14 350 29.579	In the channel (a) 7.65 8.50 8.86 At the entrance of the roadstead of Bordeaux. (b) 7.60 9.14 9.36	5.69 6.19 6.55 5.64 6.83 7.05	2.50 3.24 3.60 2.45 3.88 4.10	(c) 1 107 3 350 4 302	....
3 Dunkirk.........	1 360 454 3 180 311	1 155 600 2 609 958	4 976 5 087	6.00 8 60 8.60	4.25 6.85 6.85	0.10 2.80 2 80	1 675 7 266 7 266	9 9 9
4 Rouen..........	878 064 2 431 485	894 058 2 062 309		Channel of access between Rouen and the sea. 7.20 7.40 7.40 Port 7.00 8.50 9.00	5.30 5.50 5.50 5.00 6.65 7.15	0.40 0 60 0.60 (a) 3.85 5.45 5.95	3 528 4 994 5 940	....
5 St. Nazaire......	710 647 1 698 588	501 196 1 292 325	....	8.80 8.80 (a) 10 50	7.00 7.00 (a) 8.70	3.30 3.30 (a) 5.00	1 606 4 275 .... 4 275	.... 1 1
6 Boulogne........	871 359 1 563 527	435 628 532 044	13 500 44 705	Interior port. 7.65 (a) 12.90 (b) 12.65 Exterior port. (c) 16.90	5.00 (a) 10.28 (b) 10.03 (c) 14.28	0.90 (a) 4.36 (b) 4.11 (c) 8.36	1 248 2 038 2 038 (d) 1 000	1 8
7 Calais.	844 566 1 376 481	265 388 426 255	2 390 1 910	7.25 10.00 11.00	5.35 8.10 9.10	0.25 3.00 4.00	(a) 765 (b) 3 275 (c) 3 470	1 1 1

APPENDIX No. 1.

Administration of Public Works.

—Conditions of Working and of Access.—Development of Quays and Cost of Works

Length of useful quay (in meters).			Expenses for works of construction and improvement (in francs).				
Full depth of water.	Shallow water.	Total.	Incurred before 1876.	Incurred from 1876 to 1891.	Total, including 1891.	Remaining to be done for the completion of the works declared of public benefit.	Probab date o com- pletio
8	9	10	11	12	13	14	15
I. Ports of the English Channel and the Ocean. 1st. Principal ports, having in 1891 a traffic of over 800 000 tonnage capacity.							
8 000 11 565 (b) 12 065	654 1 985 (b) 2 385	8 654 13 550 (b) 14 550	95 000 000	(c) 68 324 988	(e) 163 324 988	3 000 000	1894
(c) 1 107 3 350 4 302	....	(c) 1 107 3 350 4 302	21 412 828	42 238 145	(d) 63 650 973	(d) 20 150 000	(e)
1 675 7 266 7 266	900 900 900	2 575 8 166 8 166	(a) 38 000 000	66 000 000	104 000 000	28 000 000	(b) 1895
3 528 4 994 5 940	....	3 528 4 994 5 940	(b) 22 645 409	(b) 28 867 272	(b) 51 512 681	(b) 9 338 388	....
1 606 4 275 .... 4 275	.... 103 103	1 606 4 378 .... 4 378	18 798 548	17 427 298	36 225 846	(b) 2 500 000	1895
1 248 2 038 2 038 (d) 1 000	1 467 880 880	2 715 2 918 2 918 (d) 1 000	14 000 000	23 430 000	37 430 000	15 370 000	....
(a) 765 (b) 3 275 (c) 3 470	1 450 1 450 1 450	2 215 4 725 4 920	10 000 000	42 520 000	52 520 000	3 155 000	1895

The notes to which reference is made may be found on the pages following the table.

orks for Maritime Commercial Ports to January 1st, 1892.

cs).	Subsidies given to the State (in francs).		
Probable date of completion.	Subsidies given or to be given by cities, departments and Chambers of Commerce for works of improvement executed since 1876.	Existing tonnage duties granted in return for these subsidies.	Total receipts from tonnage duties from 1876 to 1891, inclusive.
15	16	17	18
1894	(d) 13 694 000	(e) 0.55 franc per ton on foreign vessels or on on French vessels coming from foreign ports; 0.30 franc when these vessels are loaded with coal, white pine or ice, in the proportion of 9 to 10.	17 623 665
(e)	(f) 10 000 000	(g) 0.60 franc (law of August 2d, 1887).	(h) 5 606 626
(b) 1895	(c) 7 500 000	0.54 franc per ton of capacity (law of September 1st, 1884, and decree of August 26th, 1890).	(e) 8 946 441
	(d) 4 500 000	0.16 franc per ton of capacity (decree of August 26th, 1890).	492 261
....	(c) 6 837 667	0.55 franc.	5 334 917
1895	(c) 3 330 000	(d) 0.50	(e) 1 519 801
....	(e) 5 932 896	(f)	3 002 631
1895	(d) 4 250 000	Passenger vessels 0.06 franc per ton of capacity. Merchant vessels 0.30 franc per ton of capacity, plus 1.75 franc per passenger going or coming (laws of January 1st, August 7th, 1884, and October 4th, 1888).	4 375 618

Note.—Figures like this { 7.20 / 7.40 / 7·40 } correspond to { 1876. / 1891. / contemplated.

Designation of the ports (arranged in order of importance).	Total tonnage capacity (in-bound and out-bound).	Goods, traffic (in tons of 1 000 kg.).	Total quantity of fish received (in tons of 1 000 kg.).	Minimum depth of water at entrance and in the channel. At high water of mean spring tide.	At high water of minimum neap tide.	At low water of minimum spring tide.	Length of u... met... Full depth of water.	Shal... wat...
1	2	3	4	5	6	7	8	9
								1st.
[8] Dieppe	814 668 1 017 732	589 930 670 766	6 050 6 513	7.67 11.67 11·67	4.97 8.97 8·97	.... 2.50 2·50	1 900 2 780 2 780	86 1 1 1 1
Total for the principal ports	11 501 915 20 741 248	7 789 994 13 559 287	41 455 87 900	....	....	....	19 829 39 543 43 136	5 2 6 4 6 8
								I. 2d. Port of se
[9] La Rochelle — Port Proper	361 654 613 647	258 945 347 026	(a) 2 882 3 913	6.38 6.53 6·53	4.88 5.03 5·03	1.73 1.88 1·88	1 363 1 710 1 710	75 7 75
[9] La Rochelle — Port of La Pallice	162 784	48 021	....	10.80 10·80	9.30 9·30	6.15 6·15	1 600 1 600	(5 5
[10] St. Malo, St. Servan	458 071 545 274	252 479 348 206	2 119 1 300	9.50 9.50 9·50	4.60 4.60 4·60	....	2 209 2 493 2 493	.... 7 7
[11] Bayonne	157 454 438 248	146 465 555 559	179 595	5.53 6.28 6·70	4.73 5.48 6·00	2.38 3.13 3·65	1 080 2 060 2 170	....
[12] Rochefort	225 258 411 563	183 490 364 681	....	11.12 11.12 11·12	8.93 8.93 8·93	5.88 5.88 5·88	750 1 915 1 920	8 8 8
[13] Caen-Ouistreham	280 578 408 800	258 771 443 057	271 360	Port of Caen. 4.30 4.90 7·40 Outer port of Ouistreham. 5.92 6.20 7·70	 3.00 4.00 5 80 4.00 4.60 6·10	 0.30 0.30 2·10 0.30 0.90 2·40	1 320 1 820 1 820	2 3 3
[14] Honfleur	475 116 400 308	224 675 281 598	430 430	6.60 6.60 6·60	4.50 4.50 4·50	1.00 1.00 1·00	1 362 2 205 2 205	1 1 1
[15] Nantes	379 797 380 989	448 568 459 100	591 612	4.60 6.00 6·50	3.20 4.70 5·20	1.00 2.30 2·80	6 446 7 926 8 226	....
[16] Cherbourg	512 386 371 531	135 935 243 618	202 485	6.50 8.00 8·00	4.84 6.34 6·34	0.65 2.15 2·15	8.10 8.70 8·70	6 6 6

The not

APPENDIX No. 1—(*Continued*).

Length of useful quay (in meters).			Expenses for works of construction and improvement (in francs).				
Full depth of water.	Shallow water.	Total.	Incurred before 1876.	Incurred from 1876 to 1891.	Total, including 1891.	Remaining to be done for the completion of the works declared of public benefit.	Probable date of completion.
8	9	10	11	12	13	14	15
I. Ports of the English Channel and the Ocean.							
1st. Principal ports, having in 1891 a traffic of over 800 000 tonnage capacity.							
1 900 2 780 2 780	**800** 1 118 1 150	**2 700** 3 898 3 930	19 800 000	19 400 000	39 200 000	(a) 2 100 000	1894
19 829 39 543 43 136	**5 271** 6 436 6 868	**25 100** 45 979 50 004	239 656 785	308 207 703	547 864 488	83 613 388	....
I. Ports of the English Channel and the Ocean—(*Continued*).							
2d. Port of second order, having in 1891 a traffic between 80 000 and 800 000 tonnage capacity.							
1 363 1 710 1 710	**752** 752 752	**2 115** 2 462 2 462	9 000 000	(b) 220 000	9 220 000	620 000	1895
1 600 1 600	(c) 510 510	2 110 2 110	....	20 910 000	20 910 000	1 590 000	1894
2 209 2 493 2 493	.... 792 792	**2 209** 3 285 3 285	17 798 000	11 631 000	29 429 000	393 000	1894
1 080 2 060 2 170	....	**1 080** 2 060 2 170	9 511 000	4 998 000	14 509 000	593 000	1895
750 1 915 1 920	**890** 890 890	**1 640** 2 805 2 810	3 775 709	13 581 000	(b) 17 356 709	115 000	1893
1 320 1 820 1 820	**300** 300 300	**1 620** 2 120 2 120	11 940 341	3 997 321	15 937 662	40 000	1893
1 362 2 205 2 205	**1 200** 1 800 1 800	**2 562** 4 005 4 005	8 861 000	9 547 400	18 408 400	....	....
6 446 7 926 8 226	....	**6 446** 7 926 8 226	2 254 682	(a) 28 872 000	31 126 682	2 630 000	1893
8.10 8.70 8.70	**655** 655 655	**1 465** 1 525 1 525	2 914 500	3 838 622	6 753 122	406 680	1895

The notes to which reference is made may be found on the pages following the table.

s).	Subsidies given to the State (in francs).		
robable late of com- letion.	Subsidies given or to be given by cities, departments and Chambers of Commerce for works of improvement executed since 1876.	Existing tonnage duties granted in return for these subsidies.	Total receipts from tonnage duties from 1876 to 1891, inclusive.
15	16	17	18
1894	(b) 5 422 777	0.30 franc per ton of capacity plus 1 franc per passenger going or coming (law of August 3d, 1884).	2 982 630
....	61 467 340	....	49 884 590
1895		0.25 franc (decree of August 19th, 1880).	488 244
1894	(d) 1 800 000		
1894	600 000	0.25 franc, sailing vessels; 0.30 franc, steamers; 0.10 franc, packet boats (decree of April 28th, 1886).	(b)
1895	(a) 124 000		
1893	2 242 012	0.25 franc.	106 843
1893	(a) 779 000		
....	2 848 020	0.25 franc.	1 426 560
1893	970 000	0.10 franc per ton of capacity for foreign vessels or for French vessels coming from foreign ports.	(b) 210 100
1895	909 233	0.30 franc per ton of capacity for all vessels loaded or coming to take load at the port. Rate reduced to 0.15 franc for vessels of less than 100 tons and for those doing regular service between Cherbourg and a foreign port.	(b) 326 382

NOTE.—Figures like this { 7.20 / 7 40 / 7.40 } correspond to { 1876. / 1891. / contemplated.

Designation of the ports (arranged in order of importance). 1	Total tonnage capacity (in-bound and out-bound). 2	Goods, traffic (in tons of 1 000 kg.). 3	Total quantity of fish received (in tons of 1 000 kg.). 4	Minimum depth of water at entrance and in the channel. At high water of mean spring tide. 5	At high water of minimum neap tide. 6	At low water of minimum spring tide. 7	Le… Ful… depth… wate… 8
							2…
17 Brest	189 773	135 061	963	13.50	11.30	6.50	1 62…
	364 846	221 651	790	14.50	12 30	7.50	1 62…
	....	....	....	14.50	12.30	7.50	1 62…
Tonnay Charente	209 697	195 504	....	9.32	7.13	4.08	....
	177 315	183 346	....	9.32	7.13	4.08	....
	....	....	....	9.32	7.13	4 08	....
Lorient	93 588	78 510	11	5.30	3.85	0.75	735
	157 931	86 495	440	5.30	3.85	0.75	785
	....	....	....	5.30	3.85	0 75	785
18 Les Sables	105 193	123 510	2 032	4.40	3.10	0.60	432
	151 356	142 302	2 400	5.60	4.30	1.60	674
	....	....	....	5.60	4.30	1.60	674
19 Trouville	81 033	70 149	928	5.60	3.64	0.50	680
	139 109	114 880	1 072	6.50	5.10	1.80	1 01…
	....	....	....	6 50	5.10	1.80	1 01…
20 Tréport	47 139	35 377	3 250	5.42	2.95	....	7 fly… brid…
	135 934	149 574	2 370	6.90	4.20	....	7 fly… brid…
	....	....	....	6.90	4.20	....	4 la… flyi… brid…
21 Granville	129 065	62 273	4 394	9.60	5.60	....	98…
	134 789	75 635	2 429	9.60	5.60	....	1 00…
	....	....	....	9.60	5.60	....	1 00…
22 St. Martin de Rue	135 020	44 053	....	4.20	3.20	....	57…
	119 193	24 902	....	4.70	3.70	....	60…
	....	....	....	4.70	3.70	....	60…
23 Blaye	49 691	30 955	....	3.46	2.05	— 2.00	....
	117 075	31 753	....	3.46	2.05	— 2.00	....
	....	....	....	3.46	2.05	—2.00	....
24 Fécamp	80 282	75 362	4 950 (a)	9.40	7.40	1.50	76…
	101 366	95 352	16 311	9.40	7.40	1.50	1 2…
	....	....	....	9.40	7.40	150	1 5…
Le Legue	59 305	54 388	137	8.75	6.00	....	3.7…
	83 645	69 684	175	6.25	3 50	....	3.7…
	....	....	....	5.05	2.30	....	3.7…
Total for ports of the second order	4 030 100	2 814 470	23 339	....	....	....	21 5…
	5 415 703	4 286 440	33 575	....	....	....	29 9…
	....	....	....	....	....	....	30 6…

APPENDIX No. 1—(*Continued*).

entrance	Length of useful quay (in meters).			Expenses for works of construction and improvement (in fra			
At low vater of inimum ing tide.	Full depth of water.	Shallow water.	Total.	Incurred before 1876.	Incurred from 1876 to 1891.	Total, including 1891.	Remaining to be done for the completion of the works declared of public benefit.
7	8	9	10	11	12	13	14
I. PORTS OF THE ENGLISH CHANNEL AND THE OCEAN—(*Continued*). 2d. Ports of second order, having in 1891 a traffic between 80 000 and 800 000 tonnage capacity.							
6.50	**1 625**	**695**	**2 320**				
7.50	1 625	695	2 320	17 446 652	2 131 286	19 577 938	(a) 3 680 000
7·50	1 625	695	2 320				
4.08	....	**1 120**	**1 120**				
4.08	....	1 170	1 170	882 138	99 008	981 146	
4 08	....	1 170	1 170				
0.75	**735**	**310**	**1 045**				
0.75	785	310	1 095	3 001 629	290 618	3 292 247	
0 75	785	310	1 095				
0.60	**432**	**1 155**	**1 587**				
1.60	674	1 160	1 834	8 130 041	4 219 809	12 349 850	258 548
1·60	674	1 160	1 834				
0.50	**680**	**945**	**1 625**				
1.80	1 010	561	1 571	4 086 000	2 433 315	6 519 315	400 000
1·80	1 010	561	1 571				
....	**7 flying bridges.**	**410**	**410 7 flying bridges.**				
....	7 flying bridges.	560	560 7 flying bridges.	2 900 000	4 100 000	7 000 000	2 050 000
....	4 large flying bridges.	560	560 4 large flying bridges				
....	**985**	**671**	**1 656**				
....	1 060	671	1 731	7 324 240	1 118 606	8 442 846	....
....	1 060	671	1731				
....	**574**	**400**	**974**				
....	601	436	1 037	786 981	526 926	1 313 907	2 000
....	601	436	1 073				
- 2.00	....	**6.00**	**6.00**				
- 2.00	....	6.00	6 00	244 000	5 200	249 200	
-2·00	....	6 00	6. 0				
1.50	**760**	**380**	**1 140**				
1.50	1 220	420	1 640	(b) 13 470 000	8 040 132	21 510 132	1 000 000
150	1 520	520	2 040				
....	**3.70**	**1 500**	**1 870**				
....	3.70	1 500	1 870	1 870 000	785 000	2 665 000	34 600
....	3·70	1 500	1 870				
....	**21 502**	**11 983**	**33 484**				
....	29 944	13 782	43 726	126 196 913	121 345 243	247 542 156	13 812 828
....	30 654	13 882	44 536				

The notes to which reference is made may be found on the pages following the table.

...done ...on of ...ed of	Probable date of completion.	Subsidies given to the State (in francs). Subsidies given or to be given by cities, departments and Chambers of Commerce for works of improvement executed since 1876.	Existing tonnage duties granted in return for these subsidies.	Total receipts from tonnage duties from 1876 to 1891, inclusive.
	15	16	17	18
...acity.				
	1893	(a) 63 449		
	1893	(a) 926 000	0.50 franc.	116 644
	1896	1 793 000	0.30 franc per ton of capacity from June 1st, 1885, to April 7th, 1891 (decrees of May 6th, 1885; August 25th, 1888; October 28th, 1889, and May 4th, 1890). 0.55 franc per ton of capacity (decree of April 28th, 1892).	100 620
....	....	124 900		
	1893	30 000		
	1894	(c) 1 475 000	(d) 0.75 franc per ton of capacity on vessels loaded or coming to load in port.	(e) 291 372
	1893	159 800	0.40 franc.	59 549
	....	14 844 414	....	3 126 314

e.

NOTE.—Figures like this { 7.20 / 7.40 / 7.40 } correspond to { 1876. / 1891. / contemplated.

Designation of the ports (arranged in order of importance).	Total tonnage capacity (in-bound and out-bound).	Goods, traffic (in tons of 1 000 kg.)	Total quantity of fish received (in tons of 1 000 kg.).	Minimum depth of water at entrance and in the channel. At high water of mean spring tide.	At high water of minimum neap tide.	At low water of minimum spring tide.	Length of … m… Full depth of water.	Sh… w…
1	2	3	4	5	6	7	8	
All the ports of 3d order and fishing stations....................	2 237 287 1 841 847	1 336 739 1 152 753	39 600 23 232	....	....	....	10 386 13 644 13 729	35 46 46
Total for ports of the English channel and the ocean.	17 769 302 27 998 798	11 941 203 19 008 480	104 394 144 707	....	....	....	51 716 83 131 87 519	52 66 67
1st. Mai								
25 Marseilles........................	5 365 345 10 610 719	3 322 421 5 251 648	557 1 096	....	....	(a) 7.00 7.00 7.00	....	....
26 Cette............................	999 574 2 085 581	703 982 893 475	1 423 1 128	....	....	6.00 (a) 7.00 7.00	....	....
Total for the principal ports......	6 364 929 12 696 300	4 026 393 6 145 123	1 980 2 224	....	....	....	....	....
1st. Mainland.—Ports c								
Nice	210 104 466 437	88 869 187 856	185 50	....	....	6.50 6.50 6.50	....	....
Port Vendres......................	67 743 362 833	35 741 81 714	4 4	....	....	.... 14 000	....	....
St. Louis-on-the-Rhône...........	.... 360 656	.... 245 833	19 31	....	....	6.00 5 30 5.30	....	....
La Ciotat.	162 488 235 437	10 308 19 816	204 124	....	....	6.00 6.00 6.00	....	....

The not

APPENDIX No. 1—(*Continued*).

nce	Length of useful quay (in meters).			Expenses for works of construction and improvement (in francs).				
f m de.	Full depth of water.	Shallow water.	Total.	Incurred before 1876.	Incurred from 1876 to 1891.	Total, including 1891.	Remaining to be done for the completion of the works declared of public benefit.	Probabl date of completion
	8	9	10	11	12	13	14	15
I. PORTS OF THE ENGLISH CHANNEL AND THE OCEAN—(*Continued*). 3d. Ports of third order and fishing stations.								
... ...	10 386 13 644 13 729	35 596 46 030 46 333	45 982 59 674 60 062	73 629 639	31 381 107	105 010 746	1 850 703	....
... ...	51 716 83 131 87 519	52 850 66 248 67 083	104 566 149 379 154 602	439 483 337	460 934 053	900 417 390	99 276 919	....
I. PORTS OF THE MEDITERRANEAN. 1st. Mainland.—Principal ports, having in 1891 a traffic of over 800 000 tonnage capacity.								
	....	....	(b) 8 564 13 167 13 167	(c) 62 751 408	(c) 32 202 523	(c) 94 953 931	1 930 511	1893
	....	....	6 600 (b) 8 703 8 703	19 300 000	13 806 706	33 106 706	(c) 11 560 754	1895
... ...	....	....	15 164 21 870 21 870	82 051 408	46 009 229	128 060 637	13 491 265	....
II. PORTS OF THE MEDITERRANEAN—(*Continued*). Mainland.—Ports of second order, having in 1891 a traffic of over 80 000 and less than 800 000 tonnage capacity.								
	....	....	840 1 320 1 320	477 544	3 972 024	4 449 568		
... ...	....	....	741 811 811	3 796 673	1 038 539	4 835 212	267 358	1897
	....	....	1 765 1 765 1 765	14 380 463	925 924	15 306 387		
	....	....	200 200 200	539 000	689 081	1 228 081	3 067	

The notes to which reference is made may be found on the pages following the table.

...s).	Subsidies given to the State (in francs).		
...Probable date of completion.	Subsidies given or to be given by cities, departments and Chambers of Commerce for works of improvement executed since 1876.	Existing tonnage duties granted in return for these subsidies.	Total receipts from tonnage duties from 1876 to 1891 inclusive.
15	16	17	18
....	2 841 629	....	87 506
....	79 153 383	....	53 098 410
1893	(d)		(e) 1 979 193
1895	(d) 675 000	(e) 0.05	(e) 856 345
....	675 000	....	2 835 538
...ity.			
1897			

NOTE.—Figures like this { 7.20 / 7.40 / 7.40 } correspond to { 1876. / 1891. / contemplated.

Designation of the ports (arranged in order of importance).	Total tonnage capacity (in-bound and out-bound).	Goods, traffic (in tons of 1 000 kg.).	Total quantity of fish received (in tons of 1 000 kg.).	Minimum depth of water at entrance and in the channel.			Length of usef meter	
				At high water of mean spring tide.	At high water of minimum neap tide.	At low water of minimum spring tide.	Full depth of water.	Shallow water.
1	2	3	4	5	6	7	8	9
1st. Mainland.—Ports of the								
Toulon — Old wet dock	64 973	42 863				5.80 5.80 5.80		
Toulon — Roadstead	201 510	58 348	150			5.50 5.50 5.50		
27 Boue	79 655 130 900	65 275 111 048	36 8			6.00 6.00 9.00		
28 Cannes	57 551 92 994	39 809 44 855	54 80			6.00 6.00 6.00		
Total for the ports of second order	642 514 1 850 767	282 865 749 470	50 447					
All the ports of 3d order and fishing stations	587 210 449 227	344 020 315 411	2 183 5 423					
Total for the ports on Mediterranean mainland	7 594 653 14 996 344	4 653 278 7 210 004	4 605 8 094					
Bastia — Old port	258 342	42 825	262			10.50 10.50 10.50		
Bastia — New port	367 689	36 098	180			8.50 8.50 8.50		
Ajaccio	179 703 263 816	38 296 77 663	151 110			12.00 15.00 15.00		

The notes

APPENDIX No. 1—(*Continued*).

Length of useful quay (in meters).			Expenses for works of construction and improvement (in francs).				
Full depth of water.	Shallow water.	Total.	Incurred before 1876.	Incurred from 1876 to 1891.	Total, including 1891.	Remaining to be done for the completion of the works declared of public benefit.	Probabl date of completion.
8	9	10	11	12	13	14	15
II. PORTS OF THE MEDITERRANEAN—(*Continued*).							
land.—Ports of the second order, having in 1891 a traffic of over 80 000 and less than 800 000 tonnage capacity.							
....	....	504 504 504	250 000	58 000	1 141 719		
....	....	737 737 737	833 719	....			
....	....	650 650 650	1 773 347	459 317	2 232 664	4 163 683	(*a*)
....	....	370 370 370	....	....	....	849 314	1896
....	....	5 807 6 357 6 357	22 050 746	7 142 885	29 193 631	5 283 422	
3d. Ports of third order and fishing stations.							
....	....	12 933 14 876 14 879	20 212 852	720 405	24 993 257	252 488	....
....	....	33 904 43 103 43 106	124 315 006	57 872 519	182 187 525	19 027 175	....
§ 2. Corsica.							
....	....	250 250 250	1 408 426	3 100	1 411 526		
....	....	100 360 360	3 090 504	2 514 125	5 604 629	19 741	1893
....	....	150 235 440	2 208 072	528 170	2 736 242	122 087	1893

The notes to which reference is made may be found on the pages following the table.

...cs).	Subsidies given to the State (in francs).		
...robable date of com- ...pletion.	Subsidies given or to be given by cities, departments and Chambers of Commerce for works of improvement executed since 1876.	Existing tonnage duties granted in return for these subsidies.	Total receipts from tonnage duties from 1876 to 1891, inclusive.
15	16	17	18
...acity.			
(a) 1896	(a)	0.35 franc (law of October 10th, 1891).	
....	131 801		
....	806 801	....	2 835 538
1893			
1893			

NOTE.—Figures like this { 7.20 / 7.40 / 7.40 } correspond to { 1876. / 1891. / contemplated.

Designation of the ports (arranged in order of importance).	Total tonnage capacity (inbound and out-bound).	Goods, traffic (in tons of 1 000 kg.).	Total quantity of fish received (in tons of 1 000 kg.).	Minimum depth of water at entrance and in the channel.			Length o…	
				At high water of mean spring tide.	At high water of minimum neap tide.	At low water of minimum spring tide.	Full depth of water.	Sl…
1	2	3	4	5	6	7	8	
Other ports	207 230 209 385 ……	42 820 33 692 ……	145 184 ……	…… …… ……	…… …… ……	…… …… ……	…… …… ……	…… …… ……
All the ports of Corsica	645 275 840 890	123 941 147 453	558 474	…… ……	…… ……	…… ……	…… ……	…… ……
I.—Ports of the ocean and English channel	17 767 302 27 998 798 ……	11 941 203 19 008 480 ……	104 394 144 707 ……	…… …… ……	…… …… ……	…… …… ……	…… …… ……	…… …… ……
I.—Ports of the Mediterranean. § 1. Mainland	7 594 653 14 996 344 ……	4 653 278 7 210 004 ……	4 605 8 094 ……	…… …… ……	…… …… ……	…… …… ……	…… …… ……	…… …… ……
I.—Ports of the Mediterranean. § 2. Corsica	645 275 840 890 ……	123 941 147 453 ……	558 474 ……	…… …… ……	…… …… ……	…… …… ……	…… …… ……	…… …… ……
Grand total	26 009 230 43 836 032 ……	16 718 422 26 365 937 ……	109 557 153 275 ……	…… …… ……	…… …… ……	…… …… ……	…… …… ……	…… …… ……

APPENDIX No. 1—(*Continued*).

...nce	Length of useful quay (in meters).			Expenses for works of construction and improvement (in francs).				
...f ...m ...de.	Full depth of water.	Shallow water.	Total.	Incurred before 1876.	Incurred from 1876 to 1891.	Total including 1891.	Remaining to be done for the completion of the works declared of public benefit.	Pro... da... c... ple...
	8	9	10	11	12	13	14	1...
			§ 2. Corsica—(*Continued*).					
... ...	....	....	762 1 101 1 101	1 718 156	753 852	2 224 405	749 997	.....
... ...	....	....	1 262 1 946	8 425 158	3 799 247	12 224 405	891 825	.....
			III.—RECAPITULATION.					
... ...	....	....	104 566 149 379 154 602	439 483 337	460 934 053	900 417 390	99 276 919	.....
... ...	....	....	33 904 43 103 43 106	124 315 006	57 872 519	182 187 525	19 027 175	.....
... ...	....	....	1 262 1 946 2 151	8 425 158	3 799 247	12 224 405	891 825	.....
... ...	....	....	139 732 194 428 199 859	572 223 501	522 605 819	1 094 829 320	119 195 919	.....

...rancs).		Subsidies given to the State (in francs).		
...	Probable date of completion.	Subsidies given or to be given by cities, departments and Chambers of Commerce for works of improvement executed since 1876.	Existing tonnage duties granted in return for these subsidies.	Total receipts from tonnage duties from 1876 to 1891, inclusive.
...	15	16	17	18
	....	15 000		
	....	15 000		
	....	79 153 383	....	53 098 410
	....	806 801	....	2 835 538
	....	15 000		
	....	79 975 184	....	55 933 948

REMARKS ON APPENDIX No. 1.

[1] HAVRE—

(a) Besides, 3 460 000 oysters and 3 000 000 scallops.

(b) These figures are what should be realized on the completion of the basin for petroleum now in construction, and when the improvement works are carried out.

(c) This includes the sum of 24 300 000 francs for the construction of the Tancarville Canal.

(d) 1st. Port of Havre.

	Francs.
Construction of the Bellot Basin and of two dry docks:	
Chamber of Commerce	4 011 000
Department	1 500 000
Dredging off shore:	
Chamber of Commerce	545 000
Dredging plant:	
Chamber of Commerce	890 000
Construction of a petroleum basin:	
Chamber of Commerce	600 000
Deepening of the Vauban Basin:	
Chamber of Commerce	50 000
Other sources	16 000
Rebuilding of the dock bridge:	
Chamber of Commerce	20 000
Company of the Western Railroads	30 000
Total for the Port of Havre	7 662 000

2d. Tancarville Canal.

Construction of the canal:	
Chamber of Commerce	6 000 000
City of Havre	32 000
Total for the Tancarville Canal	6 032 000

The Chamber of Commerce has made two loans to the State besides, viz.:

1st. Law of August 5th, 1874 (interest on the amount at 4½ per cent.)	6 000 000
2d. Law of May 22d, 1888	2 350 000
	8 350 000

The first of these loans was paid in 1887, before due, to the amount of 6 822 425 francs. The second loan is to be paid in six annuities, beginning in 1888.

(e) These duties are collected wholly by the Chamber of Commerce of Havre; their tender being for 11 116 000 francs out of the 13 694 000 francs of subsidies furnished for the Port of Havre and the Tancarville Canal.

[2] BORDEAUX—

(a) The channel of approach of the Port of Bordeaux has been considered to include all of the river below. It is known that this channel presents a series of shoals where the depth is a function of the normal discharge. The heavy figures refer to the highest of the bars in 1875 (that of Bec d'Ambes). The light figures refer to the highest bar in 1891 (that of Bassens). The large figures refer to the different bars of the river.

(b) The bar of Bacalan which forms the down-stream limit is considered as being in the Bordeaux roadstead.

(c) These lengths are those of the vertical quays accessible to vessels. For river boats the banks are arranged in inclined ramps, from 20 to 23% for a length of 5 450 m. and with dry walls at 45% for 4 354 m.

(d) This includes the expenses for the improvement of the Garonne below Bordeaux and for the Gironde. These expenses have reached the sum of 14 060 521 francs.

REMARKS ON APPENDIX No. 1—(*Continued*).

(*e*) The probable date of completion of the works is indeterminate. It is expected, however, to finish the new vertical quays of the port in 1894.

(*f*) Grant from the Chamber of Commerce, which has besides made several loans to the State, viz.:

	Francs.
Port of Bordeaux:	
1st. Law of May 20th, 1886 (interest, 4 per cent.)	10 000 000
2d. Law of August 5th, 1874 (interest, 4 per cent.)	4 500 000
	14 500 000
Which was repaid in 1881 before due with 18 601 224 francs.	
2d. Law of July 15th, 1885 (payable without interest in 10 years from 1886)	3 500 000
	18 000 000
Maritime Garonne and Gironde:	
Law of August 9th, 1888	24 000 000
Payable without interest in 12 years from 1888.	

(*g*) This duty has been collected since August 5th, 1887. It is designed to cover the obligation which the Chamber of Commerce contracted in order to furnish to the State a grant of 10 000 000 francs for the construction of new quays in accordance with the law of August 2d, 1887.

(*h*) This amount is made up as follows:

	Francs.
Law of August 5th, 1874, tax of 0.25 franc	1 094 106
Law of July 15th, 1885, tax of 0.12 franc	1 074 772
Law of August 2d, 1887, tax of 0.60	3 437 748
	5 606 626

3 DUNKIRK—

(*a*) From 1785 to 1845	15 000 000
Law of July 16th, 1845	8 000 000
Decree of July 14th, 1861	15 000 000
	38 000 000

(*b*) This date applies to the works in actual progress and not to the basins of the East, where the work has been provisionally suspended.

(*c*) Grant from the city and from the Chamber of Commerce of Dunkirk.

The City of Dunkirk advanced to the State besides for the works of extension (basin of Freycinet), 31 million francs, payable without interest in 20 annuities, from 1887 to 1906 (law of September 1st, 1884).

(*d*) Grant from the Chamber of Commerce of Dunkirk intended for the reconstruction of the jetty of the East, the cost of which is estimated at 4 900 000 francs.

	Francs.
(*e*) From 1876 to 1881 (tax of 0.10 franc per ton of capacity, law of December 14th, 1875. Restoration works)	466 957
From 1876 to 1882 (tax of 0.30 franc per ton of capacity, law of December 14th, 1875. Works of improvement)	1 293 383
From 1882 to 1884 (tax of 0.40 franc per ton of capacity, law of February 5th, 1882. Works of improvement)	911 221
From October, 1884, to September, 1890 (tax of 0.70 franc per ton of capacity, law of September 1st, 1884. Works of improvement)	4 613 499
From September, 1890, to December, 1892 (tax of 0.54 franc per ton of capacity, law of August 26th, 1890. Works of improvement)	1 661 331
Total receipts from 1876 to 1892	8 946 441

REMARKS ON APPENDIX No. 1—(*Continued*).

4 ROUEN—

(*a*) The water level being lower at neap tide than at spring tide, the figures opposite indicate the depths at low water of minimum neap tide which are the actual minimum depths.

(*b*) These include the expenses incurred and to be incurred for improvement works upon the Seine between Rouen and the sea.

These expenses may be separated as follows:

	Francs.
Prior to 1876	18 097 900
From 1876 to 1891	12 738 644
	80 836 544
Expenses still to be incurred	3 565 728

(*c*)

Law of December 14th, 1875, Chamber of Commerce	1 000 000
Law of August 8th, 1879 { Chamber of Commerce	1 200 000
Law of August 8th, 1879 { Department	1 000 000
Law of March 11th, 1882, Chamber of Commerce	3 166 667
Decree of October 1st, 1861, Chamber of Commerce	471 000
	6 837 667

Besides, by virtue of the law of March 11, 1885, the Chamber of Commerce advanced to the State 6 333 333 francs payable at 4% in 20 annuities, from 1887 to 1906.

5 SAINT NAZAIRE—

(*a*) The projected depths are those which will result from dredging the channel across the bar of Charpentiers now in progress and from the works at the new entrance of the port to be constructed in the axis of the basins.

(*b*) Not including the cost of the new entrance (11 800 000 francs) the works for which can be completed in 1899.

(*c*) This grant is made up as follows:

	Francs.
Improvement of the entrance of the port (law of March 28th, 1889). Chamber of Commerce	3 000 000
Deepening of the first basin (decree of January 8th, 1893). Chamber of Commerce	330 000
	3 330 000

Besides, the Department of the Loire Inférieure, in virtue of the law of January 5th, 1875, advanced 10 000 000 francs to the State in order to hasten the completion of the basin of Penhouet; this was paid in 1881 before due, the amount being 10 995 378 francs which included interest at 4 per cent.

(*d*) Tax established by the law of March 28th, 1889. It has been reduced to 0.40 franc for vessels loaded with wood and to 0.30 franc for vessels loaded with coal. The tax established by the law of January 5th, 1875, for the benefit of the department reached 0.53 franc; it was collected to 1881.

(*e*) This includes 879 670 francs collected from 1876 to 1881, in compliance with the law of January 5th, 1875.

6 BOULOGNE—

(*a*) Exterior channel.

(*b*) Channel between the jetties.

(*c*) Exterior pass.

(*d*) Quay of the Traverse where the depth of water will be 5 m. at low tide.

REMARKS ON APPENDIX No. 1—(*Continued*).

(*e*) This amount is made up as follows:

	Francs.
Law of June 17th, 1878, Chamber of Commerce	600 000
Gift from the City of Boulogne	132 896
Law of September 1st, 1884, Chamber of Commerce	2 000 000
Law of October 4th, 1888, Chamber of Commerce	3 200 000
	5 932 896

By virtue of the law of September 1st, 1884, the Chamber of Commerce advanced to the State 4 000 000 francs besides, payable at 4% in 15 yearly payments from 1887 to 1901.

(*f*) For freight, tax of 0.10 to 0.60 franc per ton according to the kind of traffic, the number of shipments and the quantity of freight shipped or received. For passengers, taxes of 0.50, 0.875 or 1.75 francs per passenger embarked or disembarked, according to the class, the destination or the nationality of the passengers (law of October 4th, 1888, and decree of July 9th, 1889).

The tax of 0.10 to 0.60 franc will be reduced to one-fourth or to one-half if the vessel unloads or loads a chartered number of tons not over one-half or three-fourths the tonnage capacity corresponding to its legal capacity (decree of August 6th, 1890).

7 CALAIS—

(*a*) This includes 2.25 m. for the tidal quay where one finds at low tide a depth of 2.50 to 3 m., sufficient for passenger packet boats.

(*b*) This includes 550 m. for the quay of the maritime station and 250 m. for the south quay of the outer harbor.

(*c*) This includes 550 m. for the quay of the maritime station and 445 m. for the south quay of the outer harbor and the new tidal quay where the depth will be 7 m.

(*d*) Gift from the Chamber of Commerce, which, besides, has advanced 12 450 000 francs, 8 450 000 francs of which will be repaid with interest at 4% in 20 annual payments from 1887 to 1906 (law of September 1st, 1884) and 4 000 000 francs without interest in 17 equal instalments (law of December 4th, 1888).

The Chamber of Commerce also advanced 9 023 300 francs for the construction of works under the law of December 14th, 1875; this was repaid in 1881, before due by 9 748 366 francs which included interest at 4 per cent.

8 DIEPPE—

(*a*) The works still to be done consist in the construction of a dry dock and the completion of the terre-pleins.

	Francs.
(*b*) Gift of the Chamber of Commerce representing different interests	4 960 000
Remaining from the decree of February 21st, 1863	417 777
Gift from the City of Dieppe	45 000
	5 422 777

The Chamber of Commerce has, besides, advanced 4 950 000 francs payable at 4% in 12 annual payments from 1887 to 1898 (law of September 3d, 1884).

9 LA ROCHELLE, PORT PROPER, PORT OF LA PALLICE—

(*a*) From small fisheries only. The codfish from the Grand Banks and from Iceland are included in the goods traffic.

(*b*) Not including the cost of the junction works of the Morans canal with the port which has increased the useful length of the landing stage by 347 m.

(*c*) This includes 300 m. the length of certain parts of the jetties which present a platform 7 m. wide and 210 m. the length of the flying bridges of the outer harbor. These are not, properly speaking, stranding quays. Upon the 300 m. of jetties and upon 100 m. of flying bridges, ships of less than 5-m. draft will float at all times; upon 110 m. of flying bridges, ships of less than 7-m. draft will float at all times.

(*d*) Loan from the city and from the Chamber of Commerce (law of April 2d, 1880).

The City of La Rochelle advanced to the State 3 950 000 francs payable without interest in four payments beginning in 1891 (law of August 14th, 1888).

REMARKS ON APPENDIX No. 1—(*Continued*).

[10] ST. MALO, ST. SERVAN—

(*a*) Loan from the Chamber of Commerce of St. Malo for the completion of the wet dock (decree of April 28th, 1886).

(*b*) The receipt of the duties only began in 1892.

[11] BAYONNE—

(*a*) Loan from the City of Bayonne for improvement works.

The Chamber of Commerce has also advanced to the State 760 000 francs payable without interest in four annual payments beginning in 1890 (law of March 18th, 1889).

[12] ROCHEFORT—

(*a*) Mean depth of the Charente in the commercial harbor.

(*b*) This includes 2 435 441 francs dedicated to the improvement of the maritime Charente.

(*c*) This loan is divided as follows:

	Francs.
Improvement of the maritime Charente	200 000
Dry dock	197 012
3d. Wet dock	1 460 000
Say, for the City of Rochefort	1 857 012
Installations of plant by the Chamber of Commerce—sheds and storehouses	385 000
	2 242 012

(*d*) Tonnage duty for the benefit of the City of Rochefort by decree of May 23d, 1887, and law of July 23d, 1892.

[13] CAEN-OUISTREHAM—

	Francs
(*a*) City of Caen	408 000
Department	371 000
	779 000

[14] HONFLEUR—

(*a*) City of Honfleur	600 000
Department	600 000
Chamber of Commerce	1 648 020
	2 848 020

[15] NANTES—

(*a*) This includes the expenses for the maritime canal of the lower Loire, which amounts to 26 160 francs.

(*b*) Tonnage duty collected by the Chamber of Commerce of Nantes since April 1st, 1889, by virtue of the law of March 28th, 1889.

[16] CHERBOURG—

(*a*) This loan is made up as follows:

	Francs.
Law of February 3d, 1880—Improvement, City	250 000
Law of February 3d, 1880—Improvement, Department	250 000
Construction of a rail upon the quay Napoleon—City	13 333
Law of January 19th, 1885—Improvement, Chamber of Commerce	350 000
Construction in the outer harbor of a little port of shelter for fishing boats—Department and City	42 000
Extension of the rail of the quay Napoleon—City	3 900
	909 233

In accordance with the law of January 19th, 1885, the Chamber of Commerce has advanced to the State, besides, 850 000 francs payable at 4% from 1887 to 1901.

(*b*) Duty collected since January 1st, 1881 (decree of September 22d, 1880).

REMARKS ON APPENDIX No. 1—(*Continued*).

17 BREST—

(*a*) By decision of August 8th, 1890, the administration has under consideration a project for the construction of a *slip en travers* designed to replace the dry dock provided by the law of April 5th, 1883. The Chamber of Commerce would contribute 180 000 francs towards the cost and take charge of the operation of this apparatus by the help of a tonnage tax.

18 LES SABLES—

(*a*) Loan from the city for the improvement of the quay of the Remblai.

19 TROUVILLE—

		Francs.
(*a*)	Commune of Trouville	180 000
	Commune of Deauville	43 000
	Department	203 000
	Chamber of Commerce	500 000
		926 000

20 TRÉPORT—

(*a*)	Law of April 3d, 1880.		
	Department		500 000
	City of Tréport		100 000
	Chamber of Commerce of Dieppe		30 000
	Chamber of Commerce of Tréport		33 000
	M. le Comte de Laris		30 000
			693 000
	Decree of April 28th, 1892.		
	Department	200 000	
	Chamber of Commerce of Dieppe	900 000	
			1 100 000
			1 793 000

21 GRANVILLE—

(*a*)	The City of Granville	13 300
	The department	26 600
	Deepening of the 2d wet dock	
	Decree of March 19th, 1883	
	The city	42 500
	The department	42 500
	Dry docks	
		124 900

22 ST. MARTIN DE RUE—

(*a*) The works executed at St. Martin from 1876 to 1891 consist in the improvement of the entrance and the construction of a new entrance lock for the wet dock. The sill of this lock is at the height 0.77 m. above the 0 of the marine charts, while the sill of the old lock was 1.80 m. above. But the channel at the entrance of the port and the bottom of the wet dock are about 0.50 m. above the sill of the new lock; it follows that the projected improvement will not be fully completed until these high bottoms have been removed.

23 BLAYE—

(*a*) The depths given are average depths in the channel.

24 FÉCAMP—

(*a*) This number includes only the fish landed at Fécamp. The vessels fitted out at Fécamp caught, in 1891, 19 548 tons of fish.

(*b*) First cost of works for the port since its establishment.

REMARKS ON APPENDIX No. 1—(*Continued*).

	Francs.
(*c*) Department	500 000
City	150 000
Chamber of Commerce	825 000
	1 475 000

(*d*) Only the Chamber of Commerce of Fécamp profits by this tax.

It was only 0.50 franc per ton of capacity from January 1st, 1881, to May 1st, 1885.

(*e*) The collection was only commenced January 1st, 1891.

25 MARSEILLES—

(*a*) Minima depths of water.

1st. In the channel of the old port .... 7 m.

2d. In the channel of the Major at the entrance of the Joliette .... 8 m.

3d. In the channel of the Pinede .... 16 m.

(*b*) These figures show the development of the useful quays for shipping and receiving goods at the interior of the basins, only, if one adds the quays of the repair basins of the channels and outer harbors, one finds—

In 1876 .... 12 573 m.

In 1891 .... 18 118 m.

(*c*) These expenses may be separated as follows:

	Before 1876.	From 1876 to 1891	To Oct. 31st, 1891.
State	48 930 738	27 174 806	76 105 544
City of Marseilles	174 077	....	174 077
Chamber of Commerce	1 400 000	....	1 400 000
Compagnie des Docks	12 246 573	5 027 717	17 274 310
Totals	62 751 408	32 202 523	94 953 931

These expenses do not include those for equipment:

By the Chamber of Commerce	50 000	6 025 796	6 075 796
By the Compagnie des Docks	16 511 877	784 381	17 295 658
Totals	16 561 877	6 810 177	23 371 454

(*d*) The Compagnie des Docks has contributed to the works authorized by the decree of July 6th, 1875 (fitting out the quays and exterior dikes) the sum of 1 098 500 francs.

(*e*) In accordance with the law of August 5th, 1874, the Chamber of Commerce of Marseilles advanced to the State 17 483 304 francs for works of improvement of the port under the law of July 8th, 1881, and it was at the same time authorized to receive a tonnage tax of 0.10 franc which was collected until July 1st, 1883, and which amounted to 1 979 193 francs.

26 CETTE—

(*a*) The sea level varies in general from 0.90 to 1 m.; the depth of 7 m. is the minimum measured after the winter storms and before the beginning of the summer dredging. In the autumn the minimum depth is 7.50 m. The acquisition of the new dredging plant will perhaps permit of an improvement in the situation.

(*b*) These figures include the quay for large shipping which has a total length of 5 999 m. and the quay for internal navigation.

(*c*) This includes the cost of the postponed works which will reach the sum of 7 534 363 francs.

REMARKS ON APPENDIX No. 1—(*Continued*).

(*d*) Grants from the Department of l'Herault, from the city and from the Chamber of Commerce, each of which must furnish 225 000 francs to be divided into 15 annual payments of 15 000 francs. The P. L. M. Railroad Company is to furnish a grant of 2 000 000 francs for the Harbor of Tranqueville (postponed works) in exchange for land to be taken from the sea.

(*e*) The law of June 14th, 1878, has conceded to the Chamber of Commerce a tonnage tax which ceased to be collected in 1883.

The law of March 18th, 1889, authorized the Chamber of Commerce to advance 6 400 000 francs to the State for improvement works, payable without interest and to collect a statistical tax of 0.10 franc per ton or per package exported or imported at Cette. This tax has already amounted to 576 901 francs.

27 BOUE—

(*a*) The execution of the most important work is postponed indefinitely.

28 CANNES—

(*a*) The City of Cannes is to furnish a subsidy of 300 000 francs for works of improvement authorized by the decree of July 15th, 1891.

APPENDIX No. 2.

Foreign French Commerce for the Years 1891, 1875, 1859, 1847

Tonnage of loaded vessels—Weight and Value of the Carg

	1891.			1875.			
	Loaded vessels. Capacity in thousands of tons.	Merchandise. Weight in thousands of tons.	Merchandise. Value in millions of francs.	Loaded vessels. Capacity in thousands of tons.	Merchandise. Weight in thousands of tons.	Merchandise. Value in millions of francs.	Loaded vessels. Capacity in thousands of tons.
I. Imports:							
By sea — French vessels	4 587	15 974	1 658	2 544	7 781	1 224	1 628
By sea — Foreign vessels — Carrying the flag of the country from which they come	6 070		1 176	3 509		1 050	2 002
By sea — Foreign vessels — Other flags	4 352		1 464	1 736		620	373
Total imports by sea	15 009	15 974	4 298	7 789	7 781	2 894	4 003
By land	....	10 748	1 640	....	7 206	1 568	....
Total imports	....	26 722	5 938	....	14 987	4 562	....
II. Exports:							
By sea — French vessels	4 462	4 920	1 740	2 338	3 539	1 302	1 473
By sea — Foreign vessels — Carrying the flag of the country from which they come	3 720		1 238	2 522		1 377	1 291
By sea — Foreign vessels — Other flags	1 945		228	819		528	272
Total exports by sea	10 127	4 920	3 206	5 679	3 539	3 207	3 036
By land	....	3 952	1 525	....	2 803	1 600	....
Total exports	....	8 872	4 731	....	6 342	4 807	....
III. Imports and exports combined:							
By sea	25 136	20 894	7 504	13 468	11 320	6 101	7 039
By land	... ...	14 700	3 165	....	10 009	3 168	....
Total	....	35 594	10 669	....	21 329	9 269	....

(1) The statistics do not give the weight of merchandise previous to the year 1859.

(2) The separation of the values by flags has been made for the years 1847 and 1827 by applying the percentage of a 10-year a

DIX No. 2.

YEARS 1891, 1875, 1859, 1847 AND 1827.

Veight and Value of the Cargoes.

	1875.			1859.			1847.		1827.	
e.	Loaded vessels. Capacity in thousands of tons.	Merchandise.		Loaded vessels. Capacity in thousands of tons.	Merchandise.		Loaded vessels. Capacity in thousands of tons.	Merchandise. Value in millions of francs. (2)	Loaded vessels. Capacity in thousands of tons.	Merchandise. Value in millions of francs. (2)
francs.		Weight in thousands of tons.	Value in millions of francs.		Weight in thousands of tons. (1)	Value in millions of francs.				
58	2 544	7 781	1 224	1 628	3 768	683	916	443	398	212
76	3 509		1 050	2 002		681	1 269	399	409	125
64	1 736		620	373		78	624	80	67	29
98	7 789	7 781	2 894	4 003	3 768	1 442	2 809	922	874	366
40	....	7 206	1 568	....	4 690	707	....	368	....	200
38	....	14 987	4 562	....	8 458	2 149	....	1 290	....	566
40	2 338	3 539	1 302	1 473	2 098	889	673	339	393	205
38	2 522		1 377	1 291		1 049	678	398	347	
28	819		528	272		139	146	59	93	
06	5 679	3 539	3 207	3 036	2 098	2 077	1 497	796	833	445
25	....	2 803	1 600	....	863	678	....	253	....	157
31	....	6 342	4 807	....	2 961	2 755	....	1 049	....	602
04	13 468	11 320	6 101	7 039	5 866	3 519	4 306	1 718	1 707	811
65	....	10 009	3 168	....	5 558	1 385	......	621	....	357
69	....	21 329	9 269	....	11 419	4 904	....	2 339	....	1 168

applying the percentage of a 10-year average to the total value for each of these years.

of francs. (2)
212
125
29
366
200
566
205
445
157
602
811
357
1 168

APPENDIX No. 3.

French Maritime Commerce with Foreign Countries and the Colonies.

Traffic with countries upon: 1st. European seas and the Mediterranean (Algeria not included). 2d. Seas outside of Europe (colonies not included). 3d. The colonies (including Algeria).

Classified under French and foreign flags for both steam navigation and navigation by sailing vessels for the year 1875.

Foreign Maritime Commerce for the year 1875—Steam Navigation.

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
International Coast Trade (Algeria not included).												
1st. French vessels	849 098	10 670	859 768	1%	759 539	105 736	865 275	12%	1 608 637	116 406	1 725 043	6%
2d. Foreign vessels—												
Direct navigation	2 482 758	227 369	2 710 127	8%	1 992 053	866 713	2 858 766	30%	4 474 811	1 094 082	5 568 893	19%
Circuit navigation	307 520	16 242	323 762	5%	123 840	138 544	262 384	52%	431 360	154 786	586 146	26%
Total for foreign vessels	2 790 278	243 611	3 033 889	8%	2 115 893	1 005 257	3 121 150	32%	4 906 171	1 248 868	6 155 039	20%
Grand total	3 639 376	254 281	3 893 657	6%	2 875 432	1 110 993	3 986 425	27%	6 5 4 808	1 365 274	7 880 082	17%
Percentage for French vessels	23%	4%	22%	....	26%	8%	21%	... .	24%	8%	21%	

APPENDIX No. 3—(*Continued*).

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
To Distant Ports (French Colonies not included).												
1st. French vessels	269 479	....	268 479	....	283 085	100	283 185	....	552 564	100	552 664	
2d. Foreign vessels—												
Direct navigation	49 610	....	49 610	....	7 158	470	7 628	6%	56 768	470	57 238	0.8%
Circuit navigation	344 645	....	343 645	....	368 779	747	369 526	0.2%	713 424	747	714 171	0.1%
Total for foreign vessels	394 255	....	394 255	....	375 937	1 217	377 154	0.3%	770 192	1 217	771 409	0.1%
Grand total	663 734	....	653 734	....	659 022	1 317	660 339	0.2%	1 322 756	1 317	1 324 073	
Percentage for French vessels	40%	....	40%	....	42%	7%	42%	....	41%	7%	41%	

RECAPITULATION.

INTERNATIONAL COAST TRADE AND TO DISTANT PORTS (French Colonies not included).

1st. French vessels	1 118 577	10 670	1 129 247	0.9%	1 042 624	105 836	1 148 460	9%	2 161 201	116 506	2 277 707	5%
2d. Foreign vessels--												
Direct navigation	2 532 368	227 369	2 759 737	8%	1 999 211	867 183	2 866 394	30%	4 531 579	1 094 552	5 626 131	19%
Circuit navigation	652 165	16 242	668 407	2%	492 619	139 291	631 910	22%	1 144 784	155 533	1 300 317	11%
Total for foreign vessels	3 184 533	243 611	3 428 144	7%	2 491 830	1 006 474	3 498 304	28%	5 676 363	1 250 085	6 926 448	18%
Total	4 303 110	254 281	4 557 391	5%	3 534 454	1 112 310	4 646 764	23%	7 837 564	1 366 591	9 204 155	14%
Percentage for French vessels	4%	4%	24%	....	29%	9%	24%	....	27%	8%	24%	

FRENCH COLONIES.

Algeria — French vessels	516 616	271	516 887	....	532 818	33 805	566 723	5%	1 049 534	34 076	1 083 610	3%
Algeria — Foreign vessels	41 936	....	41 936	....	5 188	6 327	11 515	55%	47 124	6 327	53 451	11%
Other colonies — French vessels	1 364	....	1 364	....	2 188	....	2 188	....	3 552	....	3 552	
Other colonies — Foreign vessels	1 366	....	1 366	....	3 997	....	3 997	....	5 363	....	5 363	
Total — French vessels	517 980	271	518 251	....	535 106	33 805	568 911	5%	1 053 086	34 076	1 087 162	3%
Total — Foreign vessels	43 302	....	43 302	....	9 185	6 327	15 512	40%	52 487	6 327	58 814	10%
Grand total	561 282	271	561 553	....	544 291	40 132	584 423	6%	1 105 573	40 403	1 145 976	3%
Percentage for French vessels	92%	100%	92%	....	98%	84%	97%	....	95%	84%	94%	

APPENDIX No. 3—(*Continued*).

Navigation by Sailing Vessels.

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Cargoes.	Ballast.	Total.	
International Coast Trade (Algeria not included).												
1st. French vessels..................	442 734	102 242	544 976	18%	348 838	273 325	622 163	43%	791 572	375 567	1 167 139	32%
2d. Foreign vessels—												
Direct navigation..............	823 209	104 204	927 413	11%	498 395	564 493	1 062 888	53%	1 321 604	668 697	1 990 301	33%
Circuit navigation.............	647 627	14 516	662 143	2%	202 284	456 559	658 843	69%	849 911	471 075	1 320 986	35%
Total for foreign vessels.	1 470 836	118 720	1 589 556	6%	700 679	1 021 052	1 721 731	59%	2 171 515	1 139 772	3 311 287	34%
Grand total.....................	1 913 570	220 962	2 134 532	10%	1 049 517	1 294 377	2 343 894	55%	2 963 087	1 515 339	4 478 426	33%
Percentage for French vessels.......	23%	46%	25%	....	33%	21%	26%	....	26%	24%	26%	

To Distant Ports (French Colonies not included).

1st. French vessels	242 118	740	242 858	0.3%	221 575	29 713	251 288	11%	463 693	30 453	494 146	6%
2d. Foreign vessels—												
Direct navigation	153 677	1 527	155 204	0.9%	24 693	68 031	92 724	73%	178 370	69 558	247 928	28%
Circuit navigation	348 561	574	349 135	0.1%	99 916	185 714	285 630	65%	448 477	186 288	634 763	29%
Total for foreign vessels	502 238	2 101	504 339	0.4%	124 609	253 745	378 354	·67%	626 874	255 846	882 693	28%
Grand total	744 356	2 841	747 197	0.3%	346 184	283 458	629 642	45%	1 090 540	286 299	1 376 839	20%
Percentage for French vessels	32%	26%	32%	....	64%	10%	39%	....	42%	10%	35%	

RECAPITULATION.

International Coast Trade and to Distant Ports (French Colonies not included).

1st. French vessels	684 852	102 982	787 834	13%	570 413	303 038	873 451	34%	1 255 265	406 020	1 661 285	24%
2d. Foreign vessels—												
Direct navigation	976 886	105 731	1 082 617	9%	523 088	632 524	1 155 612	54%	1 499 974	738 255	2 238 229	32%
Circuit navigation	996 188	15 090	1 011 278	1%	302 200	642 273	944 473	69%	1 298 388	657 363	1 955 751	33%
Total for foreign vessels	1 973 074	120 821	2 093 895	5%	825 288	1 274 797	2 100 085	60%	2 798 362	1 395 618	4 193 980	33%
Grand total	2 657 926	223 803	2 881 729	7%	1 395 701	1 577 835	2 973 536	53%	4 053 627	1 801 638	5 855 265	30%
Percentage for French vessels	25%	46%	27%	....	40%	19%	29%	....	30%	22%	28%	

APPENDIX No. 3—(*Continued*).

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Cargoes.	Ballast.	Total.	
French Colonies.												
Algeria — French vessels	41 695	....	41 695	2%	21 305	6 994	28 299	24%	63 000	6 994	69 994	10%
Algeria — Foreign vessels	15 800	400	16 200		6 678	14 601	21 279	68%	22 478	15 001	37 479	40%
Other colonies — French vessels	121 715	112	121 827	4%	113 156	6 696	119 852	5%	334 871	6 808	241 679	2%
Other colonies — Foreign vessels	28 504	1 417	29 921		8 738	5 563	14 301	38%	37 242	6 980	44 222	15%
Total... French vessels	163 410	112	163 522	3%	134 461	13 690	148 151	9%	297 871	13 802	311 673	4%
Total... Foreign vessels	44 304	1 817	46 121		15 416	20 164	35 580	56%	59 720	21 987	81 701	26%
Grand total	207 714	1 929	209 643	0.9%	147 877	33 854	183 731	18%	357 591	35 783	393 374	9%
Percentage for French vessels	78%	5%	78%	....	89%	40%	80%	....	83%	38%	79%	

APPENDIX 3—(*Continued*).

SAIL AND STEAM NAVIGATION COMBINED.

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
INTERNATIONAL COAST TRADE (Algeria not included).												
1st. French vessels	1 291 832	112 912	1 404 744	8%	1 108 377	379 061	1 487 438	25%	2 400 209	491 973	2 892 182	17%
2d. Foreign vessels—												
Direct navigation	3 305 967	331 573	3 637 540	9%	2 490 448	1 431 206	3 921 654	36%	5 796 415	1 762 779	7 559 194	23%
Circuit navigation	955 147	30 758	985 905	3%	826 124	595 103	921 227	64%	1 281 271	625 861	1 907 132	32%
Total for foreign vessels	4 261 114	362 331	4 623 445	7%	2 816 572	2 026 309	4 842 881	41%	7 077 686	2 388 640	9 466 326	25%
Grand total	5 552 946	475 243	6 028 189	7%	3 924 949	2 405 370	6 330 319	37%	9 477 895	2 880 613	12 358 508	23%
Percentage for French vessels	23%	23%	23%	....	28%	15%	23%	....	25%	17%	23%	

APPENDIX 3—(*Continued*).

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
To Distant Ports (French Colonies not included).												
1st. French vessels	511 597	740	512 337	0.1%	504 660	29 813	534 473	5%	1 016 257	30 553	1 046 810	2%
2d. Foreign vessels—												
Direct navigation	203 287	1 527	204 814	0.7%	31 851	68 501	100 352	68%	235 138	70 028	305 166	22%
Circuit navigation	693 206	574	693 780	....	468 695	186 461	655 156	28%	1 161 901	187 035	1 348 935	13%
Total for foreign vessels	896 493	2 101	898 594	0.2%	500 546	254 962	755 508	33%	1 397 039	257 063	1 654 102	15%
Grand total	1 408 090	2 841	1 410 931	....	1 005 206	284 775	1 289 981	22%	2 413 296	287 616	2 700 912	10%
Percentage for French vessels	36%	23%	36%	....	50%	10%	41%	....	42%	10%	38%	

RECAPITULATION.

INTERNATIONAL COAST TRADE AND TO DISTANT PORTS (French Colonies not included).

1st. French vessels	1 803 429	113 652	1 917 081	5%	1 613 037	408 874	2 021 911	20%	3 416 466	522 526	3 938 992	13%
2d. Foreign vessels—												
Direct navigation	3 509 254	333 100	3 842 354	8%	2 522 299	1 499 707	4 022 006	37%	6 031 553	1 832 807	7 864 360	23%
Circuit navigation	1 648 353	31 332	1 679 685	2%	794 819	781 564	1 576 383	49%	2 443 172	812 896	3 256 068	24%
Total for foreign vessels	5 157 607	364 432	6 522 039	6%	3 317 118	2 281 271	5 598 389	40%	8 474 725	2 645 703	11 120 428	23%
Grand total	6 961 036	478 084	7 439 120	6%	4 930 155	2 690 145	7 620 300	35%	11 891 191	3 168 229	15 959 420	21%
Percentage for French vessels	25%	23%	25%	....	32%	15%	26%	....	28%	16%	26%	

FRENCH COLONIES.

Algeria — French vessels	558 311	271	558 582	....	554 223	40 799	595 022	6%	1 112 534	41 070	1 153 604	3%
Algeria — Foreign vessels	57 736	400	58 136	6%	11 866	20 928	32 794	64%	69 602	21 328	90 930	23%
Other colonies — French vessels	123 079	112	123 191	....	115 344	6 696	122 040	5%	238 423	6 808	245 231	2%
Other colonies — Foreign vessels	39 870	1 417	31 287	4%	12 735	5 563	18 298	30%	42 605	6 980	49 585	14%
Total. French vessels	681 390	383	681 773	....	669 567	47 495	717 062	6%	1 350 987	47 878	1 398 835	3%
Total. Foreign vessels	87 606	1 817	89 423	2%	24 601	26 491	51 092	51%	112 207	28 308	140 515	20%
Grand total	768 996	2 200	771 196	2%	694 168	73 986	768 154	9%	1 463 164	76 186	1 539 550	4%
Percentage for French vessels	88%	17%	88%	....	96%	64%	93%	....	92%	62%	90%	

APPENDIX No. 4.

French Maritime Commerce with Foreign Countries and the Colonies.

Traffic with countries upon: 1st. European seas and the Mediterranean (Algeria not included). 2d. Seas outside of Europe (Colonies not included). 3d. The Colonies (including Algeria and Tunis).

Classified under French and foreign flags for both steam navigation and navigation by sailing vessels for the year 1891.

Navigation by Sailing Vessels.

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
International Coast Trade (Algeria and Tunis not included).												
1st. French vessels	158 579	15 582	174 161	8%	134 444	94 250	228 694	41%	293 023	109 832	402 855	27%
2d. Foreign vessels—												
Direct navigation	429 381	75 168	504 549	14%	238 209	619 103	857 312	72%	667 590	694 271	1 361 861	50%
Circuit navigation	339 094	13 985	353 079	4%	173 451	295 122	468 573	62%	512 545	309 107	821 652	37%
Total for foreign vessels	768 475	89 153	357 628	10%	411 660	914 225	1 325 885	68%	1 180 135	1 003 378	2 183 513	45%
Grand total	927 054	104 735	1 031 789	10%	546 104	1 008 475	1 554 579	64%	1 473 158	1 113 210	2 586 368	43%
Percentage for French vessels	17%	14%	16%	....	24%	9%	14%	....	19%	9%	15%	

To Distant Ports (French Colonies not included).

1st. French vessels	60 063	....	60 063	....	25 014	20 758	45 772	45%	85 077	20 758	105 835	19%
2d. Foreign vessels— Direct navigation	151 755	....	151 755	....	1 194	26 328	27 552	95%	152 949	26 328	179 277	14%
Circuit navigation	639 887	....	639 887	....	101 711	134 930	236 641	57%	741 598	134 930	876 528	15%
Total for foreign vessels	791 642	....	791 642	....	102 905	161 258	264 163	61%	894 547	161 258	1 055 805	15%
Total	851 705	....	851 705	....	127 919	182 016	309 935	58%	979 624	182 016	1 161 640	15%
Percentage for French vessels	7%	....	7%	....	19%	11%	14%	....	8%	11%	9%	

RECAPITULATION.

International Coast Trade and to Distant Ports (French Colonies not included).

1st. French vessels	218 642	15 582	234 224	6%	159 458	115 008	274 466	41%	387 100	130 590	503 690	25%
2d. Foreign vessels— Direct navigation	581 136	75 168	656 304	11%	239 403	645 431	884 834	72%	820 539	720 599	1 541 138	46%
Circuit navigation	978 981	13 985	992 966	1%	275 162	430 052	705 214	60%	1 254 143	444 037	1 698 180	26%
Total for foreign vessels	1 560 117	89 153	1 649 270	5%	514 565	1 075 483	1 590 048	67%	2 074 682	1 164 636	3 239 318	35%
Grand total	1 778 759	104 735	1 883 494	5%	674 023	1 090 491	1 864 514	63%	2 452 782	1 295 226	3 748 008	34%
Percentage for French vessels	12%	14%	12%	....	23%	9%	14%	....	15%	10%	13%	

APPENDIX No. 4—(*Continued*).

		Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
FRENCH COLONIES.													
Algeria and Tunis	French vessels.	7 234	2 951	10 185	29%	4 643	10 265	14 908	68%	11 877	13 216	25 093	52%
	Foreign vessels.	8 935	....	8 935	....	10 102	4 333	14 435	30%	19 037	4 333	23 370	18%
Other Colonies....	French vessels.	53 955	....	53 955	....	58 913	2 243	61 156	3%	112 868	2 243	115 111	1%
	Foreign vessels.	53 858	....	33 858	....	20 253	2 103	22 356	9%	54 111	2 103	56 214	3%
Total	French vessels.	61 189	2 951	64 140	4%	63 556	12 508	76 064	16%	124 745	15 459	140 204	11%
	Foreign vessels.	42 793	....	42 793	....	30 355	6 436	36 791	17%	73 148	6 436	79 584	8%
Grand total..................		103 982	2 951	106 933	2%	93 911	18 944	112 855	16%	197 893	2 895	219 788	9%
Percentage for French vessels......		58%	100%	60%	....	67%	66%	67%	....	63%	71%	63%	

APPENDIX No. 4—(*Continued*).

STEAM NAVIGATION.

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
INTERNATIONAL COAST TRADE (Algeria and Tunis not included).												
1st. French vessels	1 902 761	87 033	1 989 794	4%	1 835 280	368 779	2 204 059	16%	3 738 041	455 812	4 193 853	10%
2d. Foreign vessels—												
Direct navigation	4 830 127	282 971	5 113 098	5%	3 393 105	2 476 754	5 869 859	42%	8 223 232	2 759 725	10 982 957	25%
Circuit navigation	1 903 742	63 593	1 967 335	3%	943 943	1 644 415	2 588 358	63%	2 847 685	1 708 008	4 555 693	37%
Total for foreign vessels	6 733 869	346 564	7 080 433	4%	4 337 048	4 121 169	8 458 217	48%	11 070 917	4 467 733	15 538 650	28%
Grand total	8 636 630	433 597	9 070 227	4%	6 172 328	4 489 948	10 662 276	42%	14 808 958	4 923 545	19 732 503	24%
Percentage for French vessels	22%	20%	21%	......	29%	8%	20%	......	25%	9%	21%	

APPENDIX No. 4—(*Continued*).

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded	In ballast	Total.		Loaded.	In ballast	Total.		Loaded.	In ballast.	Total.	
To Distant Ports (French Colonies not included).												
1st. French vessels	862 456	4 262	866 718	0.4%	869 561	30 200	899 761	3%	1 732 017	34 462	1 766 479	2%
2d. Foreign vessels—												
Direct navigation	658 980	....	658 980	....	87 024	42 408	129 432	32%	746 004	42 408	788 412	5%
Circuit navigation	1 287 674	38 024	1 325 698	2%	634 286	47 926	682 212	7%	1 921 960	85 950	2 007 910	4%
Total for foreign vessels	1 946 654	38 024	1 984 678	1%	721 310	90 334	811 644	11%	2 667 964	128 358	2 796 322	4%
Grand total	2 809 110	42 286	2 851 396	1%	1 590 871	120 534	1 711 405	7%	4 399 981	162 820	4 562 801	3%
Percentage for French vessels	30%	10%	30%	......	54%	25%	52%	......	39%	21%	38%	......

RECAPITULATION.

INTERNATIONAL COAST TRADE AND TO DISTANT PORTS (French Colonies not included).

1st. French vessels	2 765 217	91 295	2 856 512	3%	2 704 841	398 979	3 103 820	12%	5 470 058	490 274	5 960 332	8%
2d. Foreign vessels—												
Direct navigation	5 489 107	282 971	5 772 078	4%	3 480 129	2 519 162	5 999 291	41%	8 969 236	2 802 133	11 771 369	23%
Circuit navigation	3 191 416	101 617	3 293 033	3%	1 578 229	1 692 341	3 270 570	51%	4 769 645	1 793 958	6 563 603	27%
Total for foreign vessels	8 680 523	384 588	9 065 111	4%	5 058 358	4 211 503	9 269 861	45%	13 738 881	4 596 091	18 334 972	25%
Grand total	11 445 740	475 883	11 921 623	4%	7 763 199	4 610 482	12 373 681	37%	19 208 939	5 086 365	24 295 304	20%
Percentage for French vessels	24%	19%	23%	......	34%	8%	25%	......	28%	9%	24%	

FRENCH COLONIES.

Algeria and Tunis	French vessels	1 352 264	2 889	1 335 153	0.2%	1 320 127	9 442	1 329 569	0.7%	2 672 391	12 331	2 684 722	0.4%
	Foreign vessels	79 244	1 341	80 585	1%	43 678	43 644	87 322	49%	122 922	44 985	167 907	26%
Other colonies	French vessels	126 004	4 154	130 158	3%	150 225	1 186	151 411	0.7%	276 229	5 340	281 569	2%
	Foreign vessels	59 030	......	59 030	......	17 874	......	17 874	......	76 904	......	76 904	......
Total	French vessels	1 478 268	7 043	1 485 311	0.4%	1 470 352	10 628	1 480 980	0.7%	2 948 620	17 671	2 966 291	0.6%
	Foreign vessels	138 274	1 341	139 615	0.9%	61 552	43 644	105 196	41%	199 826	44 985	244 811	18%
Grand total		1 616 542	8 384	1 624 926	0.5%	1 531 904	54 272	1 586 176	3%	3 148 446	62 656	3 211 102	2%
Percentage for French vessels		91%	84%	91%	......	96%	19%	93%	......	93%	28%	92%	

APPENDIX 4—(*Continued*).

FOREIGN MARITIME COMMERCE FOR THE YEAR 1891.—SAIL AND STEAM COMBINED.

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
INTERNATIONAL COAST TRADE (Algeria and Tunis not included).												
1st. French vessels	261 340	102 615	2 163 955	4%	1 969 724	463 029	2 432 753	19%	4 031 064	565 644	4 596 708	12%
2d. Foreign vessels—												
Direct navigation	5 259 508	358 139	5 617 647	6%	3 631 314	3 095 857	6 727 171	46%	8 890 822	3 453 996	12 344 818	27%
Circuit navigation	2 242 836	77 578	2 320 414	3%	1 117 394	1 939 537	3 056 931	63%	3 360 230	2 017 115	5 377 345	37%
Total for foreign vessels	7 502 344	435 717	7 938 061	5%	4 748 708	5 035 394	9 784 102	51%	12 251 052	5 471 111	17 722 163	30%
Grand total	9 563 684	538 332	10 102 016	5%	6 718 432	5 498 423	12 216 855	44%	16 282 116	6 036 755	22 318 871	27%
Percentage for French vessels	22%	19%	21%	....	29%	8%	19%	....	24%	9%	20%	

To Distant Ports (French Colonies not included).

1st. French vessels	922 519	4 262	926 781	0.4%	894 575	50 958	945 533	5%	1 817 094	55 220	1 872 314	3%
2d. Foreign vessels—												
Direct navigation	810 735	....	810 735	....	88 218	68 736	156 954	44%	898 953	68 736	967 689	7%
Circuit navigation	1 927 561	38 024	1 965 585	2%	735 997	182 856	918 853	19%	2 663 558	220 880	2 884 438	7%
Total for foreign vessels	2 738 296	38 024	2 776 320	1%	824 215	251 592	1 075 807	23%	3 562 511	289 616	3 852 127	7%
Grand total	3 660 815	42 286	3 703 101	1%	1 718 790	302 550	2 021 340	....	5 379 605	344 836	5 724 441	6%
Percentage for French vessels	27%	10%	25%	....	52%	16%	46%	......	33%	15%	32%	

RECAPITULATION.

International Coast Trade and to Distant Ports (French Colonies not included.)

1st. French vessels	2 983 859	106 877	3 090 736	3%	2 864 299	513 987	3 378 286	15%	5 848 158	620 864	6 469 022	9%
2d. Foreign vessels—												
Direct navigation	6 070 243	358 139	6 428 382	5%	3 719 532	3 164 593	6 884 125	45%	9 789 775	3 522 732	13 312 507	26%
Circuit navigation	4 170 397	115 602	4 285 999	2%	1 853 391	2 122 393	3 957 784	53%	6 023 788	3 237 995	8 261 783	27%
Total for foreign vessels	10 240 640	473 741	10 714 381	4%	5 572 923	5 286 986	10 859 909	48%	15 813 563	5 760 727	21 574 290	26%
Grand total	13 224 499	580 618	13 805 117	4%	8 437 222	5 800 973	14 238 195	40%	21 661 721	6 381 591	28 043 312	24%
Percentage for French vessels	22%	18%	22%	....	33%	8%	23%	....	26%	9%	23%	

APPENDIX 4—(*Continued.*)

		Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
French Colonies.													
Algeria and Tunis.	French vessels.	1 359 498	5 840	1 365 338	0.3%	1 324 770	19 707	1 344 477	1%	2 684 268	55 547	2 709 815	0.8%
	Foreign vessels.	88 179	1 341	89 520	1%	53 780	47 977	101 757	47%	141 958	49 318	191 277	25%
Other colonies....	French vessels.	179 958	4 154	184 113	2%	209 138	3 429	212 567	1%	389 097	7 583	396 680	1%
	Foreign vessels.	92 888	....	92 888	....	38 127	2 103	40 230	5%	131 015	2 103	133 118	1%
Total.....	French vessels...	1 539 457	9 994	1 549 451	0.6%	1 533 908	23 136	1 557 044	1%	3 073 365	33 130	3 106 495	1%
	Foreign vessels..	181 067	1 341	182 408	0.7%	91 907	50 080	141 987	35%	272 974	51 421	324 395	15%
Grand total................		1 720 524	11 335	1 731 859	0.6%	1 625 815	73 216	1 699 031	4%	3 346 339	84 551	3 430 890	2%
Percentage for French vessels......		89%	88%	89%	....	94%	31%	91%	....	91%	39%	90%	

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

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605.

(Vol. XXIX.—July, 1893.)

INLAND TRANSPORTATION.

By Captain F. A. Mahan, Corps of Engineers, U. S. A.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Transportation is about the most important question entering into the exchange of products from different parts of the world. Where transportation exists free and untrammeled, there the exchange of products takes place readily, and this exchange, which is known as commerce, is increased or diminished almost in exact proportion to the facility with which the articles to be exchanged can be transferred from one point to another.

Transportation means simply a carrying across; that is to say, across some space which lies between the point of production and the point of consumption. Modes of carrying vary in different parts of the world, and civilization might almost be expressed in terms of ease of transfer. In savage countries we find transportation, even for long

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

distances, carried on by means of porters; from this we rise through many gradations of pack and draft animals, of vehicles more or less primitive and cumbersome, of vessels propelled by poles, by oars or by sails, and so on, until is reached the highest development of carriage by land or by sea, with steam as the present best motor. But who shall forecast the future, who shall say that development will not continue, or who shall tell what the coming years may bring forth?

It is proposed in this paper to consider the two means of transportation most used in the United States, and to make, if possible, some comparison between them. These means are rail and water. There is little use made of other sorts except within short distances of certain centers, and as the conditions vary greatly from center to center, there seems to be no way of comparing results.

There must be some point from which to start in making comparisons between rail and water transportation. The point which naturally suggests itself is the consideration of the articles which are mostly carried in common by each highway. The investigation must also have some limits assigned so as to have somewhat assimilated conditions. For example, it would be folly to attempt comparison between a railway joining two points between which water communication cannot be had, and a water-way joining two points between which rail communication cannot be had. As it is more easy to dispose of the limits to which this paper is to be confined than to consider the articles carried on both highways, they will be considered first.

If the United States be studied with care, it will be found that the greatest amount of population and of commercial activity lies in an east and west belt containing the New England and Middle States and those of the Western States lying between the Ohio and Missouri rivers and the Great Lakes. Within these limits are found the great cities of New York, Chicago and Philadelphia, together with those of less degree, such as Portland, Me., Boston, Baltimore, Pittsburgh, Buffalo, Cincinnati, Cleveland, Detroit, Duluth, St. Louis and many others, to mention all of which would lead far beyond what is required in an article so general in its character as this.

This belt contains the most important transportation routes of the country. From New York leads west the route by the Hudson River, the Erie Canal and the Great Lakes. From the same point lead the great railroad routes—the Pennsylvania, the New York Central

and Hudson River, the Erie, the Delaware, Lackawanna and Western, the Lehigh Valley, the Baltimore and Ohio, the New York, West Shore and Buffalo. From Pittsburgh starts the Ohio River, which joins the combined Upper Mississippi and Missouri at Cairo. These three streams form that great river, the Mississippi, one of the main highways of commerce of the country.

The boundaries of the field over which it is proposed to travel being fixed, it may be well to see on what ground the lines of transportation mentioned above may be placed, so as to form some sort of comparison between them; in other words, are there any articles of merchandise carried by both to such an extent as to give the means of comparing one with the other? It will therefore be well to consider what is carried along these routes, and to find whence it comes and whither it goes.

The articles which seek the water routes are generally of the bulky sort, in the delivery of which time enters but little, but which must come regularly, so that the supply may be maintained continuously. Ore, for example, or coal or grain is eminently suited to water carriage. Neither deteriorates appreciably by reason of slow transportation. If a given number of tons per day be required, it is only the average which need be maintained, as it matters little whether the per diem average be delivered daily, or twice the amount on alternate days, or thrice the amount twice a week. This class of goods has been found, by universal experience, to be best adapted to water transportation. M. Fleury says, in speaking of the parts played by water and railways in France: "The only elements of traffic which can be divided between the water-way and the railway are raw materials and agricultural products, which, as a rule, can only stand a low rate of carriage, and which go frequently in large quantities and over long distances." The same is true of this country. Grain and timber follow the lakes and the Erie Canal. Ore and coal follow the lakes so far as possible. Coal follows the Ohio and Mississippi.

Where, then, are the sources of supply? Where are the points of distribution and concentration? What are the routes followed? How does the cost of transportation compare by rail and by water?

The grain supply comes largely from the western and north-western part of the field mentioned. The supply from the northwest is concentrated at Duluth, at the extreme end of Lake Superior; that

from the western part comes in at Chicago. Iron ore comes from the south shore of Lake Superior. Anthracite coal comes from the north-eastern part of Pennsylvania, and bituminous coal from western Pennsylvania and West Virginia. The concentration of grain at Duluth and Chicago is by rail. It is moved from Chicago mainly by way of the lakes to Buffalo, whence it goes on its eastward journey to New York by canal and rail. The rail shipments from Duluth direct to eastern ports become important. Large quantities of grain go by the lakes to Buffalo, as is the case with Duluth. After leaving the Straits of Mackinac, the route followed by the Chicago grain is the same as that followed by the Duluth grain after leaving the mouth of the St. Mary's River. In each case the transportation is now by large iron or steel steamers, carrying from 60 000 to 120 000 bushels at a trip. The iron ore comes from sundry ports on the south shore of Lake Superior, some in Michigan, some in Wisconsin, and others again in Minnesota. It is carried in large vessels to Cleveland and other points on Lake Erie, and thence by rail to the furnaces at Pittsburgh and elsewhere.

Anthracite coal is carried by rail from north-eastern Pennsylvania mainly to Buffalo. At this place it is loaded into the vessels which carry it to many of the lake ports—Chicago, Detroit, Duluth, and others. The bituminous coal of western Pennsylvania and some from West Virginia comes down the Monongahela in boats, barges or flats, two or three at a time, to Pittsburgh, where the larger tows are made up to go down the Ohio River.. The great tows for the lower Mississippi are prepared at Louisville.

Bituminous coal is also carried from western Pennsylvania to Erie and other lake ports near at hand, and thence it goes by water to the port nearest to its destination.

In the transportation of any sort of materials, the item of cost is the one which occupies the most important place. The question, so far as the cost of moving grain from Chicago to New York is concerned, has been carefully studied. This transportation presents three features: 1st, all water transportation, that is to say, by the lakes to Buffalo and thence to New York by way of the Erie Canal and Hudson River; 2d, all rail from Chicago to New York; 3d, water to Buffalo and rail thence to New York. The average freight rates for a bushel of wheat from Chicago to New York, for each year from 1868 to 1891, is

given in the following table, taken from the last annual report of the New York Produce Exchange.

Year.	Average Rates per Bushel.			Year.	Average Rates Per Bushel.		
	By Lake and Canal.	By All Rail.	By Lake and Rail.		By Lake and Canal.	By All Rail.	By Lake and Rail.
	Cents.	Cents.	Cents.		Cents.	Cents.	Cents.
1868.......	22.79	42.6	29.0	1880.......	12.27	19.9	15.7
1869.......	25.12	35.1	25.0	1881.......	8.19	14.4	10.4
1870.......	17.10	33.3	22.0	1882.......	7.89	14.6	10.9
1871.......	20.24	31.0	25.0	1883.......	8.37	16.5	11.5
1872.......	24.47	33.5	28.0	1884.......	6.31	13.12	9.55
1873.......	19.19	33 2	26.9	1885.......	5.87	14.00	9.02
1874.......	14.10	28.7	16.9	1886.......	8.71	16.50	12.00
1875.......	11.43	24.1	14.6	1887.......	8.51	15.74	12.00
1876.......	9.58	16.5	11.8	1888.......	5.93	14.50	11.00
1877.......	11.24	20.3	15.8	1889.......	6.89	15.00	8.70
1878.......	9.15	17.7	11.4	1890.......	5.85	14.31	8.50
1879.......	11.60	17.3	13.3	1891.......	5.96	15.00	8.53

During the year 1891 there was received at New York 124 844 643 bushels of grain by rail. In this quantity are included flour and meal. Let it be assumed that all this grain had been taken to Buffalo or Erie by lake, and from these ports sent to New York by rail. Had it all gone to Buffalo and thence been carried by canal and river, the saving in the cost of transportation would have been $2\frac{57}{100}$ cents on each bushel, giving a total saving of $3 208 500, an item worth considering.

On the Ohio River is found the chance of comparing directly the cost of carrying coal by river with the cost of carrying it by rail. The Pittsburgh Coal Exchange gives the following rates per ton to the various points mentioned.

	By rail.	By river.	Saving by river.
Wheeling, W. Va..........	$0.70	$0.08	$0.62
Parkersburg, W. Va........	1.25	0.14	1.11
Cincinnati, O..............	1.70	0.46	1.24
Louisville, Ky.............	2.45	0.53	1.92
St. Louis, Mo..............	2.50	1.45	1.05

The cost of the river transportation includes the cost of returning the empty packages to Pittsburgh. These packages are not of the sort to be utilized for return freight, being entirely open and built for no other purpose than that of carrying coal.

The following table shows the effect of competing river routes on railway freight rates. The figures contained therein were given by the Louisville, Ky., Board of Trade. They are suggestive of what may be expected whenever the use of water-ways is abandoned. The rates given are those for freight carried by rail to the points mentioned. It will be noticed that New Orleans is twice as far from Louisville as either Aberdeen, Winona or Grenada, yet the rate to New Orleans is much less than to any of the other points. Why is this? Simply because there is a water route by way of the Ohio and Mississippi rivers from Louisville to New Orleans.

From Louisville, Ky., to—	Rates in Cents per 100 lbs.									
	Distance.	Class.						Bagging and Ties.	Packing House Products.	Flour in Sacks.
	Miles.	1	2	3	4	5	6	A	B	C
New Orleans, La.	811	90	75	65	50	40	35	25	25	25
Jackson, Miss.	565	114	94	81	68	56	49	41½	43	40
Aberdeen, Miss. ... about	400	114	94	73	62	51	46	38	40	32½
Winona, Miss.	408	119	97	80	66	54	47	43	46	37
Grenada, Miss.	395	118	97	80	65	54	47	43	45	40

From Louisville, Ky., to—	Distance.	Grain.	Beer in Wood.	Liquors in Wood.	Flour in Barrels. Per Barrel.	Special Iron.	
	Miles.	D	E	H	F	L. C. L.	C. L.
New Orleans, La.	811	20	28	25	45	25	18
Jackson, Miss.	565	32	53	55	78	32	26½
Aberdeen, Miss. ... about	400	26	37	42	57	31	29
Winona, Miss.	408	31	48	48	66	36	29
Grenada, Miss.	395	33	48	54	70	42	36

Special iron list includes nails, bolts, rivets, spikes, fence wire, roofing iron, bar, rod, sheet and band iron, horse and mule shoes, plow molds, plow points, etc.

Classes 1, 2, 3, 4, 5 and 6 include different classes of merchandise, which is classified according to value, weight, liability to damage, etc.

The distance to New Orleans, the point farthest away, is 2.053 times that to Grenada, the nearest point; yet the cost of transportation to

the former is the following per cent. of transportation to the latter, according to the classes in the table.

Class 1	76 per cent.	Class A	58 per cent.
" 2	77 "	" B	55 "
" 3	81 "	" C	60 "
" 4	77 "	" D	60 "
" 5	74 "	" E	58 "
" 6	74 "	" H	46 "
		" F	64 "
		L. C. L	60 "
		C. L	50 "

If, therefore, Grenada had the advantage of water transportation it might have rail freight rates of about one-third of what they are at present.

These two cases, of coal from Pittsburgh and general merchandise from Louisville, show the great advantages to be gained by the competition of water routes by river. They are a repetition of what was found to be the case in the carriage of grain from the West to the East. But, it may be argued, these data are for long distances and are not of value in determining rates when the distances are less. To answer this the writer quotes from Professor James' "The Canal and the Railway":

"The Guthrie Ice Company was engaged for several years in shipping ice from Willow Springs to Chicago by canal—14 miles—and from Summit to Chicago by rail—9 miles. The cost per railroad was 50 cents per ton; by canal, 18 cents, the toll being $5 on each boat carrying 125 tons of ice. The rate per ton-mile on the railroad was 5.55 cents, and on the canal 1.29. The boats were empty one way, and the load had to be moved against a current of 1¼ miles per hour in a contracted channel having a cross-section of only about three times the area of that presented by the loaded boat.

"The Bodenschatz and Earnshaw Company of Chicago gave the rates at the same date—October, 1886—per cord of stone from their quarries in Lemont to the city as follows: By rail, $4.50; by canal, $1.95. The Excelsior Stone Company gave the rate as $3.90 and $1.73, respectively."

The water-ways of France and Germany also show economy of transportation when heavy bulky materials are to be carried. The more the question is studied, the more desirable the use of water-ways becomes. It is evident by the great attention which many nations are

bestowing on their navigable highways that there is something real, something tangible, in the economic results to be obtained by water carriage. What some of these economic results may be in the United States, with properly constructed and well-organized water routes, is dimly foreshadowed in what has been already briefly given.

The traffic carried on the lakes in the way of freight is enormous. During the year 1890 the amount of freight transported was 2 003 047 tons to and from foreign ports, and 28 295 959 tons between domestic ports. This domestic trade may be classified as follows:

	Tons.		Tons.
Wheat	807 906	Salt	280 187
Corn	1 769 138	Cement	98 937
Oats	348 216	Stone	323 890
Barley	141 197	Lumber	5 843 421
Rye	42 609	Shingles	134 461
Flaxseed	79 086	Lath	56 660
Flour	922 056	Miscellaneous lumber products	835 118
Mill stuff	161 138	Miscellaneous freight	1 414 750
Coal	5 735 299		
Iron ore	9 132 761	Total	28 295 959
Pig iron	128 145		
Copper	40 894		

All freight traffic between ports on Lakes Erie and Ontario and ports on Lakes Huron, Michigan and Superior must pass through the Detroit River. The net freight tonnage carried on this highway in 1890 was 21 888 472 tons. The vessel tonnage, entrances and clearances in the foreign trade at London in the same year was 13 480 769; and at Liverpool for the same year it was 10 941 800, or for the two, 24 422 569 tons. This total is less by 3 873 390 tons than the domestic lake tonnage of the United States, and greater than the freight passing Detroit by only 2 534 097 tons.

The actual freight passing through the Sault Ste. Marie Canal during each of the last three years was—

9 041 213 tons in 1890
8 888 759 " 1891
11 214 333 " 1892

During the seven months of navigation, May to November, inclusive, in 1891, the amount of freight taken eastward from Chicago was

4 265 934 tons, as stated by the report of the Chicago Board of Trade. Of this amount 2 705 084 tons went by lake, and 1 560 850 tons went by the following railroads: Grand Trunk, Michigan Central, Lake Shore, Pittsburgh, Fort Wayne and Chicago, Pan Handle, Erie, Baltimore and Ohio, Wabash, and Nickel Plate.

As a matter of curiosity it may be interesting to see what would be required in the way of rolling stock if the attempt were made to carry by rail all the domestic lake traffic of the United States. The most powerful freight locomotive, Class "R," used on the Pennsylvania railroad, running at 15 miles per hour on a level and straight track, can exert a pull of 15 300 lbs. This at 3 lbs. per ton-weight of train would draw a train-weight of 5 100 tons under favorable conditions. If the train were made up of heavily loaded cars (*i. e.*, 41 tons each total), there would be 124 vehicles. Taking the average live weight at 25 tons to the car, there would be required 1 131 835 cars, or 9 128 trains of 124 cars each. Allowing for wet tracks, for curves and grades and for other unfavorable conditions, the theoretical number of cars may be reduced to 41 per train, which would increase the number of trains to 27 384, giving 117 trains per day for the 234 days of navigation.

Still, with all the advantages offered by water routes, the tendency of freight is to be absorbed more and more by the railways, except where natural lines of water communication exist of such dimensions, and contain such volumes of water, as to allow the running of vessels of large size. Such water-ways are the Great Lakes, the Mississippi and Ohio Rivers, the Hudson River and various bays and sounds along the coasts. Where these are found, the railways cannot hope to compete for the carriage of certain lines of freight. But the improvements which are constantly made in railway practice and construction have made the iron roads formidable competitors for canals as handled in this country.

The best-known canal route, the Erie, is losing ground steadily at the present time, and the causes which are bringing about this state of affairs are in operation to an even greater extent in other parts of the country. There are also special local causes which have their influence on particular lines, but they do not enter into the general conditions.

First among the causes of the decadence of canals may be placed the entire misapprehension of the probabilities and possibilities of railways. These later lines of transportation came into being before the

canals of the United States were fairly in working order. When it is considered that but little more than 12 years had passed from the date of the opening of the Erie Canal to that of the introduction of railways, it may easily be seen that the water-way had had no opportunity of showing its capabilities when the new highway appeared. The people of this country were carried away by the ideas which rose before them. They saw the speed with which vehicles could be moved over the new roads, and there is little cause for wonder that their feelings should have overpowered their judgment. Such great and marvelous things were expected from, and predicted of, the railways, that the cause of the canals was abandoned before it was known what they could do. The quickness of the railway appealed to the imagination, and visions of what have since been found to be impossibilities began to appear.

One marked difference exists between the railway and the canal. The former owes its life to private enterprise, the latter owes it to the State. The desire for gain is necessarily the mental condition of capital. Improvement of tools is the natural result of competition. Competition between lines cannot exist when one hand controls both lines. It does exist where lines are under different managements. The wish for the greatest returns from the capital invested leads to improved means for obtaining results. The best brains turned towards capital as their work was most appreciated there. Government officials in important positions, whether under the State or under the general Government, are found to be notoriously underpaid when their responsibilities are compared with those resting on the shoulders of men occupying corresponding positions under private corporations. Capital is alive to its interests, the State is not. Private business is arranged on business principles, State affairs are not. Hence it is that during the past 50 years everything connected with railways has undergone great improvements; whereas, the water-ways have been allowed to stand still when they have not been permitted to fall into ruin. During these years, railways have been built in all sorts of places, under all kinds of conditions; experiments beyond number have been tried on everything which enters into the construction or management of railways. The results of trials, of tests, of experiments, have been collated, compared and studied carefully, and a regular and systematic practice has been developed. Conventions of railway officials from

all parts of the country are held from time to time, to consider and discuss every conceivable problem known to railway practice. Engineers take up questions of construction; master mechanics talk over and read papers on the various problems presented in the building and maintenance of rolling stock; superintendents give their experiences in the maintenance of way and handling of the lines; passenger and freight agents investigate the many ways in which business can be extended, by making lines better known, by offering advantageous rates, by insuring better connections, by expediting service and by such other methods as may be dictated by experience.

What, then, is seen as the result of so much intelligent toil? Compare the railway of to-day with its predecessor of 40 years ago, and what are the points which force themselves at once on the attention? 1st. The great improvement in the road itself; better grades; easier curves; careful ballasting; stronger bridges; heavier and steel rails with almost perfect joints between them. 2d. Increased capacity of the rolling stock; heavier locomotives with improved combustion; larger and stronger cars; better coupling; automatic brakes. 3d. System gradually introduced into management; absorption of many lines into a continuous system under uniform control; methods of soliciting and obtaining business; safety in the movement of trains; improvements at terminal points for facilitating the handling of freight and the movements of passengers.

Such, in very broad strokes, are the principal changes which have taken place. But what an expenditure of brain-power has been required to bring them about! And, having studied all these changes, what is the final result obtained? It may be expressed in one word—economy. Economy of time, and, hence, of money; because, as our proverb has it, "time is money." Economy in direct expenses, and, hence, reduction in the cost of service, as seen by the difference in the cost of carrying grain from Chicago to New York, which was, in 1868, 42.6 cents a bushel, while in 1891 it was only 15 cents, a reduction of 65 per cent.

How do these improvements manifest themselves? A rail is a beam resting on several points of support. The heavier rail bears the greater load. The durability of the steel rail is much more than that of the iron rail, while its present cost scarcely varies from that of the latter. The lighter grade gives a greater load to the same locomotive.

The easier curve reduces friction. Stronger bridges must go with stiffer rails. Careful ballasting and nearly perfect joints cause smoothness of running, and reduce wear and tear on the rolling stock by doing away with the shocks caused by inequalities in the surface of the rails. The heavier locomotive draws the heavier train. Improved methods of combustion evaporate more water, and hence obtain more work from a given weight of fuel. Larger and stronger cars carry a greater live load for a given dead load; therefore, a greater quantity of useful work for the same effort put forth. Better couplings prevent accidents and save time. Automatic brakes diminish expenses by putting the train under better and easier control, and save hands which are needed without them. System saves time and expense by enabling the same number of men to do a greater amount of work. Consolidation or absorption of many lines into one whole brings uniformity of practice, more prompt dispatch of business, and gets rid of many officials. Systematic soliciting of business brings roads into prominence and allows the shipper to know without trouble what points he can reach and how to make his shipments with the least inconvenience and greatest advantage to himself. Improved terminal facilities allow of much larger masses being handled in a given space of time. There is room for work, and confusion is removed.

These are but few of the causes which have led to the great success of railways and to their taking so commanding a position in the workings of the community. The causes are of importance in this article in order to show what has been done for the railways and what has been left undone on the minor water-ways. On those of greater importance, such as the Great Lakes and some of the more traveled rivers, many improvements have been made; but the canals are where they were 25 years ago, years during which the railways have gone ahead with their greatest strides.

Let us see if any parallel can be made between the improvements made on the railways and those which are required for canals. The prism of the canal corresponds with the roadbed of the railway. The strength of the rail finds its counterpart in the area of the cross-section of the prism. The durability of the rail is represented in a certain way by the firmness of the banks of the canal. Lighter grades are repeated in more convenient means for overcoming the step from one level to the next. Curves, ballasting and joints have no counter-

part on the water-way. Increased power in the locomotive is comparable with better means of locomotion in the canal. Improvement in combustion can be applied here as well as on the railway. Larger and stronger cars are comparable with larger and stronger boats.

In addition to these points of similarity there are others which apply alone to canals. For example: the question of rainfall in the matter of the water supply for canals is one of the highest importance, but where is it studied systematically? What experiments have been made on the traction of boats, to determine whether their present shape is that which adapts itself best to economy of the power needed for locomotion, or to learn whether improvements can be made, and, if so, what they are? One trouble with canals is the slow rate of speed which boats must hold so that the waves made by them shall do no harm to the banks; but what is done in the way of studies to determine the best mode of protection so that a higher rate of speed can be allowed without injury to the banks? The passage of a boat from one level to the next is always attended with a great loss of time. With the ordinary lock there are three phases of this operation: 1st, the boat must enter the lock; 2d, the lock must be emptied or filled so that the boat can be lowered or raised; 3d, the boat must pass out of the lock. What can be done to reduce the time required for any or all of these operations? When these different phases have to be repeated several times, as is the case with a flight of locks, the loss of time is something of great moment. If there be seven locks and it require 20 minutes to pass each one, the time required for all will be 140 minutes, or 2 hours and 20 minutes, which corresponds to a horizontal distance, traveled along a level, of 7 miles at the rate of 3 miles an hour. Leakage around lock gates is a serious question in connection with the water supply; is the construction of lock gates studied with a view to stopping these losses? And what terminal facilities, with a proper equipment of hoisting engines, sheds, storerooms, etc., have ever been considered? How should they be designed, how constructed and how arranged so that boats may be unloaded and loaded with the least loss of time? These are a few of the questions which must present themselves to him who examines even cursorily the service of a canal. They and many others are subjects of constant study abroad, and why should they not be so with us? From the nature of our institutions they

cannot be. Rotation in office is fatal to the study of any question for the solution of which time is demanded. Constant changing of the chief of an office or department prevents any settled policy from being carried out, even if some one chief have succeeded in formulating one. With a tenure of office of only one or two years, how is it possible to accomplish any good work, or bring about a lasting result? Scientific problems can be solved only by many years of devotion to collecting facts and data, to assorting and studying them, to interpreting the results and to finding the remedies for the defects. How can this work be done by a series of men, none of whom remain in office long enough to master the details of the work, much less to originate anything for improvement.

How can legislators, who rarely retain their seats for more than one or two terms, act intelligently on such matters? Scarcely do they begin to appreciate the importance of a subject when other persons are selected to take their places, and the modicum of knowledge which the outgoers have succeeded in acquiring is lost, and the incomers have to go over the same ground as their predecessors and learn the needs of the service by the same laborious methods. Legislators, moreover, are rarely schooled in scientific methods of work or in the accuracy of thought necessary for the consideration of these questions. They fail to appreciate the wisdom of the proverb of Solomon: "There is that scattereth, yet increaseth; and there is that withholdeth more than is meet, but it tendeth to poverty."

The condition of the inland navigation of the country can scarcely be called satisfactory. Aside from the Great Lakes and a few of the more important streams, navigation may be said not to exist so far as any practical uses are concerned. For the natural water-ways, which are mostly under the care of the general Government, no systematic plan on a broad and comprehensive scale has ever been adopted, and the writer is not aware that any such plan has ever been proposed. Efforts are made to improve certain streams, but each stream is treated simply as a problem in hydraulics and not as a part of a problem in commerce or transportation. The local conditions and needs of the stream are studied, but not the broad, general plan into which it may be incorporated as a link. Although the work has been localized on different streams, there has been much accomplished. We may take the cases of the Monongahela, Great Kanawha

and Tennessee rivers, all tributaries of the Ohio. Great improvements have been made on these streams; on the first, partly by private enterprise, and partly by government work; on the second and third, by the general Government alone. The main part of the work was done on the Monongahela before the general Government considered either the continuation of the improvement of this stream or the beginning of that of the others. After the work on all of these streams was undertaken, each one was under the charge of a different engineer, and the improvement of each has been carried on according to its own local conditions as a separate stream and not as a part of the great Ohio system, and still less of the greater Mississippi. But can improvements be conducted advantageously in this way if the future development of the country is to be taken into consideration? The worst feature of the case is that the same lack of system must be continued until the necessity of taking a comprehensive view of the needs of the country, in the direction of inland navigation, is forced on our legislative bodies by the strength of public opinion.

While the legislative bodies of the country usurp the functions of the executive no betterment of the case can be expected. On the continent of Europe the studies of what is needed for the improvement of lines of communication under government control are first made by the executive departments. The projects are carefully worked over, and solutions are found for all the problems which the course of the investigation raises. The order in which the various portions of an improvement should be begun is laid down, and the whole project, after having been declared to be of public utility, is submitted to the legislative body, to provide the necessary funds.

How different this system from the lack of system existing with us, where the legislative body originates and determines what is necessary and what is not, and even directs, at times, that a certain sum of money must be expended at a given point without any idea whether the sum mentioned will be too little, enough, or too much.

If the state of the natural water-ways is so poor, what may be said of that of the artificial ones? The canals have to contend, not only against lack of system in construction, but also against constant and vigorous attacks made upon them by their ignorant and prejudiced rivals, the railways, and against the apathy of the public as regards all questions which are not placed close before men's eyes. Persons

interested in railways constantly decry the canals; they claim and proclaim that the day of canals is passed; that canals have outlived their usefulness; that people will no longer submit to the slowness of canal movement in the handling and transportation of goods. This cry is taken up by certain journals (and they are numerous) which will sell their influence for a few free rides, or by others which, having made no deep study of the facts, are misled by the hue and cry started by the railways, which only desire the closing of the canals in order that rates may be raised to the highest point which the traffic will bear. This cry is repeated again by the great mass of the people who "think they think what they are taught," and who repeat like parrots what interested agents and a subsidized press have told them.

Is it true that canals are out of date and that they have outlived their usefulness? Let it be remembered that the canal of to-day varies little from the canal of 50 years ago; and remembering this, let us ask: What would be the probable state of the canals if improvements on them had kept pace with those on the railways? What, if enlarged prisms and more capacious locks had been substituted for the contracted dimensions now in use? What, if boats were propelled at greater speed, so that the distance now covered in two days could be passed over in one? The railway and the canal are both freight carriers. They may be compared to two factories which turn out the same line of goods. How would it be if one of these establishments had gone on as it did 50 years ago, without improvement, while the other had kept itself supplied with all the new machines for saving labor, for preparing the raw material and for turning out the finished product? Would not the former have been ruined long ago and would not the latter, in all probability, have become prosperous? This being so, does it not appear as though there must be a great vitality in the canal, if, having stood still, lo! these many years, it can yet hold its own against all the improvements which have been introduced on the railway?

It would be natural to assume that those who are most interested in having their work made easier and more profitable, the boatmen themselves, would be the first to call for improvements. But such does not seem to be the case. So far as canals are concerned, the mental activity of the carriers seems to be on a par with the traditional speed of their boats. The writer has heard the following objection urged

against the enlargement of the Erie Canal: "If the canal be enlarged, larger boats will be used, and our present boats will be a loss." Of course, the larger boats will drive out the smaller, but meanwhile the smaller boats must remain at work until the whole line is capable of passing the larger boats. The improvement of the canal cannot be brought about in a day, a month or a year. As it continues, the smaller boats can be retired and the improved equipment be obtained. Does a railway hesitate to adapt its track for increasing loads simply because it has on hand a large number of small cars?

Another opposition to the canals comes from the taxpayers. As the Government, whether general or state, has assumed the charge of the water-ways, the funds for their construction and maintenance must come from the public treasury, and hence be obtained by taxation. The people who live at a little distance from the line of the water-way are unable to see the indirect advantages which they gain. They see simply so many dollars paid to the state on account of canals. They do not see to what an extent the canal controls the railway rates of transportation. This is clearly shown by the action, in the Legislature of the State of New York, of the representatives from the counties of the southern tier and those from the northern and north-eastern parts of the State. These counties, being comparatively remote from the canal, do not see the benefits which they receive from it. They forget that the canal made the important cities of New York and Buffalo what they are, and that it developed the smaller towns of Rochester, Utica, Syracuse, and others along its line. They lose sight of the fact that they really receive back in the way of appropriations sums larger than their taxes, the excess being paid by the parts of the state which have become enriched by the canal.

The disregard of the interests of the people, shown by the legislatures of many of the States in neglecting their canals, is little short of a crime. For such action as turning over the canals of a state to the tender mercies of a railway, as was done by the Legislature of the State of Pennsylvania when it abandoned the canals to the Pennsylvania Railroad, it is hard to find a suitable term. It partook of the treachery of Judas. The transportation interests of the whole people of the state were sacrificed to the few who were interested in the railway. Who, traveling along the line of this road, can feel otherwise than sick at heart to see the ruins of the great canal which lay alongside of

the Juniata River; the revetments of its embankments tumbling to pieces; the locks gone to decay; and the rotting remnants of gates and gate posts at such parts of the canal as are not actually occupied by the tracks of the railway? It is a sight which mars sadly, for the thinking mind, the beauty of the country through which the line passes.

Do we find abroad any abandonment of canals comparable with what has taken place in the United States? So far as is known to the writer, Great Britain is the only country where the scare caused by the arrival of the railway brought about the actual giving up of the lines of canals. The story is a curious one, involving as it does cupidity, alarm and lack of investigation. Quoting Professor James again we find that:

"In England one of the circumstances which contributed powerfully to the ultimate victory of the railway was the extraordinary obstinacy with which canal owners clung to their high dividends, refusing to abate one jot or tittle of their high tolls, fighting the railways at all possible points, until railway managers saw that they must concentrate their efforts upon breaking down the canal opposition. Even when the canal owners saw the traffic departing from the canal for the railway, they still refused to take the only course which lay open to them, viz., the enlargement and improvement of the canals and the consequent cheapening of the tolls. When once the break was made in the case of a few great lines, and the fact became became clear that traffic was being rapidly diverted, canal owners became frightened and were willing to take what they could get for their property. It became impossible to get capital for the improvement of canals for two reasons: people began to distrust their permanent prosperity, and the railway mania, which was now fairly under way, absorbed all the capital that was to be had."

In England, as in the United States, the directors of railways saw that the best thing for them to do was to obtain possession of the canals and let them go to ruin. In 1880, in England, Scotland and Wales, out of 4 033 miles of canal and canalized river navigation 1 447 miles were in the hands of railways, 948 miles having passed under railway control in the years 1845–46–47.

Even at their best the condition of the canals was such as to render them unable to compete with the railways, not only in England, but elsewhere. They had been built on absolutely no system at all. They were simply a series of ditches of small cross-section and with insignificant locks wherewith to pass from one level to the next. The widths varied as did their depths; there was no uniform system of

tolls; there were no arrangements for the quick handling ana forwarding of freight. The capacity of a line of canal is that of its smallest prism and smallest lock. No matter how great the dimensions of the parts on either side, this smallest part controls the traffic of the whole. Unlike the grade of a railway where an extra locomotive may be used to help over with trains too heavy for one, the canal lock is an insuperable obstacle. . .

How could such lack of system stand up against the combination of the railways? It was impossible to readjust matters so as to meet the new turn of affairs. The men in control had gone along, undoubtedly, in the old ruts, and when the new opponent appeared they were unable to shake off the lethargy into which they had fallen. The rude awakening dazed their vision. Their sight was dimmed. Apparent ruin stared them in the face. Canal directors are like other people. When a wreck is threatened the cry is, "save himself who can." Undoubtedly the cause would have been far different had the canals belonged to the Government as they did in France and elsewhere on the Continent.

Even in France the influence of the railway mania was seriously felt. Under the reign of Napoleon a systematic development of the canals of France had been begun. Every year the money spent on canals increased in amount, until shortly after the introduction of railways, when the yearly expenditure fell off rapidly for some 25 or 30 years. By that time it was seen that the railways were not omnipotent; that there was traffic better fitted for the canal than for the railroad. Then the annual expenditures began to increase, both for canals and for the canalization of rivers. The invention of movable dams by Messrs. Poirée and Chanoine gave a tremendous impetus to inland navigation, and to the careful study of how best to improve the many streams which, up to that time, had run to waste. The devices and improvements of Messrs. Desfontaine, Girard, Boulé, Caméré, Jacquet, Krantz, and hosts of their fellow-workers, sent France far ahead in this improvement of her natural water-courses, while at the same time the canals were daily becoming more and more a serious study. With the practical adaptability of the French in all fiscal questions, the solution was soon found, and its result was the measure adopted while de Freycinet was Minister of Public Works, in 1879. This great scheme made all the canals of the State,

with few unimportant exceptions, of uniform gauge, if such a term may be applied to a canal. With uniform prisms everywhere, with the length and width of the locks the same in all parts of France, it will soon be possible to send a cargo from Dunkirk or Calais on the North Sea and British Channel to Marseilles on the Mediterranean, to Havre at the mouth of the Seine, or to Bordeaux just off the Bay of Biscay, without breaking bulk or disturbing the contents of a boat. Here, then, was a great advance. But is it sufficient?

In an interesting paper by M. Fleury, on the "Respective Rôles of Water-Ways and Railways in Transportation," presented at the International Congress on Inland Navigation, held at Paris a year ago, we find a partial answer:

"In the east of France, in that very region where the boating interest did so much formerly toward the creation and development of metallurgic, chemical and manufacturing interests, the quantities of heavy materials carried by rail become more and more preponderating. The transportation of fuel to Nancy by water is diminishing, whereas a notable increase marks that by rail. This is especially the case with French coal, of which the amount carried by water was, in 1886, to that carried by rail as 2.63 to 1. In 1889 this ratio had fallen to less than unity. In 1892 it had fallen to less than one-half. Iron ores from Belgium and the North also disappeared for a while from 1887 to 1889, although they now seem to be coming back. Salts and sodas are also showing at the present time a manifest preference for the railway. Cotton also from Havre to many manufacturing towns in the Vosges has largely deserted the canal. In 1890 more than 4 000 tons of this specially profitable freight was lost. The same is the case with wools. Toward the center it is noticed that charcoal, which, from time immemorial, has come to Paris by water, is now beginning to come by rail. On the Central Canal carrying coal from Decize to Creusot has disappeared since 1889. An amount of 70 000 tons, it may be said safely, has given up boats for cars in this one direction alone."

After making many comparisons between the freight rates by water and by rail, M. Fleury informs us that there are other causes than these which have destroyed certain sorts of transportation which the canals used to enjoy. For example: 141 995 tons of coal passed down the Oise in 1889 *en route* to the Lower Seine; whereas, only 108 577 passed in 1890. "This loss cannot be charged with certainty to the railways. It is more than likely that it is due to importations of English coal coming up the Seine, the increase in one year being from

68 000 to 184 000 tons, of which the boating interest got the benefit." Again he tells us that the lowest rates are not those which have done so much to divert traffic from the canals to the railways. For example: the carrying of baled cotton from Havre to the interior has mostly gone to the railroad, although the prices which the boating interest could obtain would still enable them to compete successfully with the roads. "However, in this case, as in many others, the boats have given up the fight. Why must freights by water be to-day so little below those by rail?" This question he answers as follows, and it will be seen that the causes working at home are at work abroad.

"The boating industry," says M. Fleury, "seems too often not to know that there is an inexorable law called progress; those who do not obey it must go under. Boating is now very nearly what it has long been. The traditional shape of the boat might doubtless be improved so as to give less resistance to traction; are not the methods of towing susceptible of being perfected so that, while making movement more regular, it can also be made less costly? But the way in which boating affirms its inferiority, so to speak, as regards railways, is in the lack of organization involving great losses of time and an insufficient use of vessels.

"Railways, it must be acknowledged, have made many and great advances, while boating has been standing still. Locomotives now haul 400 tons of live weight, without requiring more fuel or hands than they used formerly for only 200 tons. Tracks are stronger and better, the rolling stock is better, better oiled, whence a great reduction in resistance. It is vain to say that at $800 a car, the transportation of 300 tons by rail requires $24 000 worth of rolling stock; whereas, a boat of the same capacity only costs one-sixth as much. What does it matter provided that the cars do six times as much useful work as the boat? And this is the case. Since 1886 the railways utilized the capacity of their freight stock 37 times a year, while the boats were used but eight times. Lately the disproportion has become still more marked, although the coefficient of the utilization of boats has increased 11 per cent. Other investigations of the same sort would also lead to the conclusion that, in spite of all scientific reasons to the contrary, the cost of hauling goods by rail is not much greater than that by canal. But, I have just mentioned, it is in violation of the natural laws observed by science that the poor organization of the boating service, its routine, its distrust of new methods, its dislike for change of habits, have given rise to this shocking anomaly and allow it to exist. Boating must change if it is to continue to exist. Let it perfect its boats and improve its methods of moving its vessels. This will be accomplishing much; but, above all,

let it use its time better on the road and in those frequently long stops at ports while seeking freights in any haphazard way. Let all this be aided by a reduction in the minimum time required for passing a boat through a lock and in that needed for closing the canal for repairs. By this better use of time boating will be more sure of success in maintaining and increasing its business : rates of four-tenths of a cent per ton per mile will no longer scare it, and it will be long ere the railways can follow down to such a figure. It will remain in control of the part of the carrying trade which tradition still continues to give to it. It will have served the interests of the public as well as its own."

M. Fleury then refers to the law of 1879, which calls for a minimum depth of 6.56 ft. in the canal and locks having an available length of 126.28 ft. and width of 16.40 ft; he calls attention to the great injury done to navigation by not having the application of this law extended to all lines of canal in the country, and then urges the completion at the earliest possible moment of this great and advantageous improvement.

In spite of the dark picture drawn by M. Fleury, it will be found in a paper presented at the same congress by M. Delaunay-Belleville, that the tonnage carried by the French lines of inland navigation amounts to the respectable figure of 1 997 181 540 mile-tons for the year 1890. The railway mile-tonnage for the same year was 7 292 391 218. Hence, the freight carried by the inland lines of navigation was 27.3% of that carried by all the railways combined. The length of the waterways frequented by boats is 7 946 miles, the length of the railways is 20 667 miles ; hence, the water tonnage reduces to 251 000 tons carried the entire length of the navigable highways, and the rail tonnage to 353 000 tons carried the whole length of the railways. The average activity per mile of water-way is therefore about $\frac{7}{10}$ of the average activity per mile of railway. Finally, the average distance of transportation of a ton of freight was 79 miles by rail and 82 miles by water.

The total quantity of freight embarked on the navigable highways in 1890 reached 24 167 343 tons. The total tonnage of the French seaports, including arrivals and departures, and the three great classes of trade "Foreign, Deep-Sea Fisheries, and Coasting," was 24 814 497 tons in the same year, 1890.

The freight carried is grouped under ten different heads: Coal, building materials exclusive of wood, manures and fertilizers, firewood and timber, machinery, metallurgic industry, industrial products, agricultural products and provisions, miscellaneous articles, wood of

all sorts moved in rafts. These may be reduced to three grand divisions: 1st, products of the extractive industries, such as coal, building materials, ores and mineral fertilizers; 2d, forest and agricultural products and food supplies (including vegetable and animal manures); 3d, metallurgic and industrial products and miscellaneous articles. The quantities carried are—

Of the first class	16 161 905
" second class	6 100 045
" third class	1 905 393

The increase in the navigation traffic from 1881 to 1890, both inclusive, is as follows: the actual tonnage of freight loaded on board rose from 19 740 239 tons in 1881 to 24 167 343 in 1890, or an increase of 22.4%; the total mile-tonnage rose from 1 350 383 817 in 1881 to 1 997 181 540 in 1890, or an increase of 47.8%; the average length of haul was increased from 68.5 to 83 miles. Hence, not only did the commercial importance of the traffic increase more than 22% during this last decade, but the use of the water-ways was greatly improved, since the average length of haul of 1 ton was increased 21 per cent.

A comparison between the railway and water freights shows that the mile-tonnage increased on the canals 4.8% per year during the decade; whereas, on the railways it increased less than 1% per year in the same time.

M. Delaunay then says: "The increase in the use of the waterways must be attributed almost exclusively to their constant improvement, the increase being not less than 21%; it cannot be doubted that the gradual removal of the breaks in the uniform gauge of the canals has allowed the boats to make longer and longer trips without breaking bulk."

This sameness of gauge has been carried over a length of 1 556 miles between 1878 and 1890, and it now (1890) rules on a length of 2 462 miles of the French canals.

A great drawback to the full usefulness of the French canals is to be found, according to M. Delaunay, in the lack of technical and commercial equipment, that is, proper machines for handling, and suitable wharves, sheds, etc., for storing and sorting goods. This lack he compares with the admirable equipment of the seaports and of the large railway stations.

Large industrial establishments have frequently their own landing places, which are thoroughly well provided with everything needed

for handling freights and for storing them. "Collieries have their banks provided with all necessary machinery to load their coal under the best conditions and with a minimum of expense and waste. In the same way large consumers of fuel who settled alongside of canals and navigable streams, in order to obtain their supplies cheaply, have not been slow to provide the equipment fitted to the economical reception of their fuel.

"The same holds good with other branches of inland trade, building materials, grain and flour, wines, etc.; everywhere large producers and large consumers, guided by their interests, have set up the private plant suited to the needs of their industries.

"But wherever the interests of the public at large are in question, wherever powerful individualities have not had to interfere in their own behalf, the equipment is either lacking, or it is notoriously insufficient."

In summing up all his data M. Delaunay lays down a number of propositions, of which the following are especially germane to the subject of this paper. They are:

"The radius of attraction or expansion of inland navigation ports over the surrounding country is exceedingly limited. This situation, which follows from the nature of the freights which are the main reliance of this navigation, has not changed sensibly by reason of the insufficiency of the technical equipment (machines for loading and unloading) of the public ports, of their commercial equipment (sheds, storehouses and warehouses), and of the almost complete absence of connection between the water-ways and railways.

"The isolation of the navigation system from the railway system is a great economic blunder. Large industrial establishments have known, in their private interests, how to set an intelligent example of the simultaneous use of both means of transportation; but again most of the public ports are without the necessary appliances.

"This close connection of the rail to the wharf * * * will thus make the ports of inland navigation, not only points of industrial consumption or storage of food supplies, but true centers of commercial transactions.

"This commercial extension cannot take place without giving rise to an increase of trade from which both the boating interest and the railways will profit."

M. Delaunay's final conclusions are:

"1st. So far as the highway proper is concerned, the completion of the uniform gauge of the water-ways of the first class is the first necessity; 2d, so far as the special organization of the ports is concerned, a close connection of the water-ways with the railways is demanded."

It may not be without profit to glance at affairs in Germany, and especially in Prussia, where enormous sacrifices have been made for the improvement of the water-ways since 1880.

At the Fifth International Congress on Inland Navigation, M. Pescheck presented an interesting paper on the "Respective Rôles of Water-Ways and Railways in the Movement of Merchandise in the Basins of the Elbe and the Oder." From this paper it is learned that the basins of these streams and their tributaries cover about three-fourths of the German Empire. Within their limits are the three largest cities of Germany; Berlin, Hamburg and Breslau. Dresden, the capital of Saxony, and the great commercial cities of Magdeburg and Stettin, are also included.

After giving a brief summary of the features of these basins from the commercial standpoint we learn that—

"Prussia has undertaken to transform her water-ways so as to make it possible to carry cheaply and to great distances the goods best adapted to this form of transportation. On account of the different characters of the various basins it was impossible to lay down a given boat as a type. Only the execution of such a plan could be followed as would insure, on the one hand, a sure and quick circulation, and allow, on the other, not only the use of the present vessels and increased loads, but also the employment of large boats on deeper water. The necessity of using steam has not been lost to sight, that is, the increase in the number of towboats and steam carriers. This programme means an endeavor to have steamboats circulate freely on the canals, involving in the beginning heavy costs for strengthening the banks. To obtain these results Prussia has spent $12 500 000 since 1880," an average of about $1 250 000 a year.

The extension of the water-ways is marked by the following considerations: 1st, the large rivers of Northern Germany are naturally good highways, and this leads to joining their basins by canals; 2d, interest and national cultivation demand the regulation of the large rivers with a consequence of favoring navigation; 3d, the improvement of navigation leads to the improvement of the old canals and the opening of new.

The greater part of the water-ways are now in such condition that shippers and consigners of goods are able, as they could not formerly, to agree as to times of delivery. Hence more valuable freights now go by water than those formerly intrusted to boats.

A comparison between the amounts of wood, coal, wheat, rye, flour

and bran, pig iron and manufactured iron, carried by rail and by water, shows that of the total number of tons carried there went—

Of wood	66%	by rail and	34%	by water.
" coal	83	" "	17	"
" wheat	58	" "	42	"
" rye	32	" "	68	"
" flour and bran	62	" "	38	"
" pig iron	62	" "	38	"
" manufactured iron	95	" "	5	"

These figures apply, however, only to the six towns mentioned. For them the freights by rail are 75% of the total amount carried, and those by water are 25 per cent. The freights of the entire valleys are distributed thus : 89% by rail and 11% by water.

These comparisons show the large part played by the water-ways in the exchange of goods, in spite of the relatively very small importance of their branches as compared with those of the railways. There is reason to hope that this part will become greater as imperfections are made gradually to disappear. The establishment of a proper equipment for loading and unloading vessels has not kept pace with the development of navigation. Hence, out of the 300 days, about, in the year, during which navigation lasts, a boat is in motion only 75 days, the other 225 being given up to loading, unloading and waiting.

In Germany the State owns the railways as well as the water-ways. The development of the water-ways was scarcely disturbed when the railway system was extended. Where it was felt, a remedy was soon applied by pushing more energetically the development of the water-ways.

Under the peculiar economic conditions it is found that a canal scarcely becomes profitable until the annual amount of freight carried reaches 1 000 000 tons, and that water rates are not quite so low as rail rates. Still, there are some well-informed partisans of water-ways who maintain that water-ways, when rationally constructed and equipped, can compete perfectly well with railways.

"If, standing only on the calculation of net rates for transportation, it were desired to stop a future development of water-ways to the profit of the railways, it could not help doing harm to economic considerations. Every transportation route has a right to the protection

of the public; because civilization is propagated by facilitating every kind of communication."

M. Pescheck quotes M. Krantz, a government engineer and a senator, who used the following language at the session of the French Senate of June 12th, 1884:

"Why can canals still have at the present time earnest and convinced partisans?—and I confess to being one. It is not that any one can look upon the canal as being so complete an instrument as the railway, or nearly so; for it is not. * * * The canal brings about economy, not only by the reductions of rates which it makes, but also by those which it imposes. It is the check on the railway; and if, recalling my profession as an engineer, I could use a comparison, I should say that it is a brake—an automatic brake; no one is needed to make it work; it acts on the demand of surrounding forces; that is, of private interests. * * * It is the brake—the necessary and legitimate brake—on the railway, which preserves the government from all sorts of severe measures which it would frequently adopt and which would be rarely successful."

In Prussia no attempt is made to bring about competition between the railways and water-ways, as that is spontaneous; it comes of itself.

M. Pescheck concludes as follows:

"*First.*—The regulation of large streams by means of dikes, with the object of insuring the free flow of water at low and medium stages in an invariable minor bed, so as to prevent marshes forming along the shores, favors navigation and causes the improvement of canals, without bringing about competition with the railways.

"*Second.*—Heavy transportation can be carried on by rail and by water equally well; and the more the water-ways and their means of transportation are improved, the more they will be sought by less cumbersome freights.

"*Third.*—In order to compete with the railways, the water-ways require, above all, a more complete equipment for loading and unloading goods.

"*Fourth.*—The parts to be played respectively by the railways and water-ways of a given country depend especially on the natural conditions existing for navigation, and also on the politico-economical considerations controlling the movement of freights.

"*Fifth.*—Water-ways are more easy and effective means than special railway rates for enabling the entire public to participate in the cost of transportation on a large scale, the cheapness of which is indispensable for the prosperity of industry and agriculture.

"*Sixth.*—The creation of artificial water-ways is justified economically, as a general rule, even when the cost of construction and maintenance can only be made up by the saving accruing to the shipper

with respect to railway rates; and there is no reason to fear that the railway will be at all injured by the creation of canals."

The papers presented to the Fifth International Congress on Inland Navigation show how widely the subject of water transportation is engrossing the attention of engineers and political economists. Naturally, such conventions must call attention to their work, and the opinions which they utter must have weight. Are these conventions the forerunners of public opinion, or is the great mass of the people gradually becoming aware that there are better ways of checking the exactions of railways than a resort to tariff commissions? The testimony of Mr. Albert Fink, for a long time the head of the railway pool of the United States, is valuable in this respect. In speaking of the Erie Canal, in a letter to Senator Windom in 1878, he says:

"You are aware, sir, that when the rates are reduced between Chicago and New York, as they are always reduced on account of the opening of the canal, that this reduction applies, not only from Chicago, but from all the interior cities (St. Louis, Indianapolis, Cincinnati) to New York. If that were not the rule the result would be that the roads running from these points to Chicago would carry the freight to Chicago from which low-water or rail rates would take it to New York and thus leave the through lines from the inland cities without traffic. Hence, Philadelphia, Baltimore and Boston, though they have no direct water competition, get the advantage of reduced rates. The reduction of rates from Chicago and St. Louis to New York, Philadelphia, Baltimore, etc., reduces rates on shipments from those western points *via* New York and the ocean to Southern Atlantic ports, Norfolk, Wilmington, etc., and from there into the Interior, Augusta, Macon, etc. The direct railroads must reduce their rates correspondingly, and thus the Erie Canal determines rates all over the country, including the South, until it reaches a line where low ocean rates from New York to the Gulf cities exercise their influence upon the rates to adjacent interior points."

Here is M. Krantz's expression, that the canal is a brake on a railway, put in another shape. No one understands the transportation problem better than Mr. Fink. For this reason his words have a weight greater than those of any other man.

That the people have long had the idea that freight rates by rail are exorbitant is shown by all sorts of acts of Congress and acts of State legislatures intended to put a check on the railways—railway commissions, commerce, and inter-state commerce commissions have been created with the express intention of regulating railways. In

other words there has been an endeavor to create economic conditions by law, by mere words. It is just such a corrective as might be expected from bodies composed mainly of lawyers and not of business men. Such measures are the severe ones of which M. Krantz speaks, and which, he says, are rarely successful.

The inability of such measures to remove the abuses which they are intended to correct is causing an investigation by those interested into the means whereby a true corrective may be found. The people are gradually awakening to the fact that the true solution of the problem is by the improvement of the water-ways now existing and by the establishment of new ones. No argument can be made in the face of such a competition. No unjust and discriminating rates can be maintained by railways when the latter know that a powerful competitor stands ready to take advantage of any shortcomings. No long suits at law, with all the advantages on the side of the railways which a long purse, well-paid, and frequently unscrupulous, attorneys give, have to be borne by the unjustly treated shipper before he can obtain justice. With the water-way the remedy is at hand; it can be applied promptly and effectively. It is a remedy without appeal. This the railways know well.

Now what must be done to bring about the remedy? As all public improvements in our country must originate in the legislative bodies, and as these bodies possess, as a rule, no more information on any given subject than the masses of the people, it is necessary to begin by educating the people to the true functions and capacities of water-ways. In other words, public sentiment must be aroused on the subject, because to this sentiment the legislative bodies are generally most sensitive. Means must be taken to keep the subject of water-ways before the people. The construction and maintenance of such ways being under the control of the Government, there are no stocks or bonds to be put upon the market, and these ways are not listed at the exchange. They lie, therefore, in the background, and remain there unperceived, unless they be brought by force to the front.

The improvement of the natural water-ways presents special problems. In some the supply of water all the year round is sufficient to keep up a good navigation, provided that it be practicable to confine the stream to an artificial minor bed. In others a slack-water system, by means of locks and movable dams, will be required. In both cases

there must be a proper arrangement of landings, space in which to store freight before loading and after unloading, and special appliances for handling freight promptly.

The improvement of the artificial water-ways requires consideration according to the position which the canal holds in a chain of transportation. Where it is a highway of the first order it must be adapted to boats of large size. For a canal of such importance as the Erie, the boats should have a freight displacement of not less than 1 000 tons. The locks should be proportioned to the capacity of the trunk of the canal. It is stated that the present trunk of the Erie Canal is sufficient for boats of 650 tons, but the locks are only large enough for boats of 250 tons.

The water supply of the canal needs careful attention. A large gain in this could be made by withdrawing all privileges of taking water from the canal for any purpose whatever.

The banks of the canal must be protected to such an extent that boats can pass at a speed of at least 10 miles an hour.

At every town there should be proper places for landing cargoes. On these landings should be the necessary machinery for handling freight and the buildings in which to store it. In this connection there is a subject which must be settled before long, and that is the way in which railways have been allowed to cut off many ports from the water. Witness most of the ports of the Great Lakes! The railways, through the connivance of the authorities of several cities, have built their bulkheads and laid their tracks right on the edge of the water, and shut off the city entirely from all communication with its own water front. Under these circumstances there is no advantage from navigation to be gained by the city, because everything which reaches it is filtered through the railways which surround it, and it obtains by sufferance that which belongs to it as a right.

The motive power on the canal must be adapted to the new conditions. The days of the horse are numbered, and steam, for the present at least, must take his place. This change need not be prejudicial to the canal, because the shape of the boat may be so changed as to cause little more wash with the greater speed than there is at present with the one now in vogue.

System must be introduced in the methods of doing business. Shippers must be taught that the canal exists. Freights must be

solicited and rates made through to various points by connection with railways or steamers from the termini.

In a word, the canals must be brought up to date. They must have the benefit of the knowledge and skill of which there is such an abundance at the present day. If, when the canals become thoroughly modernized, both in appliances and in methods, a comparison be made between their capacity and that of the railways for doing business, we may rest assured that the last chapter on the subject of inland navigation will remain long unwritten.

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HISTORY OF THE CONVERSION OF THE RIVER CLYDE INTO A NAVIGABLE WATER-WAY, AND OF THE PROGRESS OF GLASGOW HARBOUR FROM ITS COMMENCEMENT TO THE PRESENT DAY.

By JAMES DEAS, C. E., Engineer Clyde Navigation.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The writer has much pleasure in complying with the invitation of the American Society of Civil Engineers, and has prepared this paper on the improvement of the River Clyde for navigable purposes, and the progress of the Harbour of Glasgow from its inception until the present day. In 1715 the first act was passed for quayage at Glasgow, the money to pay for which was obtained out of a duty of two pennies, Scots, or one-sixth of a penny sterling, on every pint of ale and beer that was vended or sold within the City of Glasgow, and privileges thereof.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

Probably for no river in Great Britain has so much been done "by art and man's device" as for the River Clyde above Port Glasgow. In fact, from a mile below Bowling upwards to Glasgow, a length of 12 miles, the Clyde of the present day is nearly as much an artificial navigation as the Suez Canal.

It is but natural that American engineers should desire to have some information regarding the improvement of the Clyde, which, though not the birthplace of steam propulsion in Europe—Dalswinton Loch, Dumfriesshire, having that never-to-be-forgotten honor 104 years ago—received into its waters at Port Glasgow in June, 1812, the *Comet*, 42 ft. long by 11½ ft. beam, 4 ft. draft, and 3 H. P., the precursor of the mighty fleet of steamships of the present day; and has played so important a part in the development of the mercantile and defensive steam navies of the world, especially in the transatlantic trade, which has brought New York and Great Britain within six days of each other, and has culminated for the present in the launching into the Clyde, within a half mile of the western boundary of the City of Glasgow, on September 8th and February 2d last, respectively, from the Fairfield Shipbuilding and Engineering Company's yard, of the steamships *Campania* and *Lucania*, each 620 ft. long by 65 ft. 3 ins. broad by 43 ft. deep.

These improvements have raised Glasgow within the short period of 90 years from a second-rate inland provincial town, with a population of 77 000, to be the second city of the Empire, with a population of 658 073, and the chief seaport of the west of Scotland; increased the value of the lands on the river's sides, from Glasgow seaward, a hundred-fold; created the burghs of Govan and Partick; given wealth to thousands, and the means of life to hundreds of thousands of the inhabitants of the northern portion of Great Britain, and emphasized in a marked degree the local epigram, "Glasgow made the Clyde, and the Clyde made Glasgow."

"The Tweed, the Annan, and the Clyde
All rise from one hillside."

But how different their careers and destinies! The Tweed, immortalized by Sir Walter Scott, falling into the North Sea at Berwick, and famous chiefly for its king of fish, the salmon; the Annan, after a quiet and pastoral course of only 35 miles, reaching its bourne in the Solway Firth at Annan; while the Clyde, after a course of 98 miles and

draining an area of 945 square miles, reaches deep water at Greenock, and thence to the Atlantic Ocean passes in its course over the famed Falls near Lanark, through the celebrated orchards of Clydesdale between Lanark and Hamilton and thence to Glasgow through the wealthy mineral district which it drains; is famed the wide world over as the creator, by its improvement, of the City of Glasgow, the home of almost every industry under the sun, and is the greatest ship-building river in the universe, furnishing to all nations the means of communication with each other by vessels built on its banks.

Numerous waters, rivulets, burns and rills join in the formation of the upper Clyde; the highest of these, which take their rise in the mountain ranges on the confines of Lanarkshire and Dumfriesshire, are the Daer Water, the Powtrail Water, and the Clyde Burn; the last 1 028 ft. above ordnance datum, where it crosses under the Caledonian Railway at the Summit Station, in a conduit 12 ft. 6 ins. wide by 2 ft. 3 ins. high.

The Daer and the Powtrail meet before their confluence with the Clyde Burn; and although the Clyde Burn is considerably smaller than either of the other two, the stream from this point takes the name of the River Clyde.

The chief tributaries of the lower Clyde are only three in number.

First.—The Kelvin, noted in song, which rises in the Campsie Hills, due north of Glasgow, forms in its lowest reach the western boundary of the City of Glasgow, and, after a course of only 21 miles, discharges into the Clyde at Govan Ferry, the western limit of the harbour.

Second.—The Cart, which joins the Clyde about ½ mile below Renfrew, and is formed by the junction, about ¾ mile from the Clyde, of the White Cart and the Black Cart; the former, about 19 miles in length rising in the Eaglesham District of Renfrewshire, about 10 miles due south of Glasgow, and on which the prosperous town of Paisley is built; and the latter, about 9 miles in length, rising in the neighbourhood of the town of Lochwinnoch.

Third.—The Leven, well known in cotton manufacturing circles for its Turkey-Red Dye Works, which discharges the surplus waters of Loch Lomond—the Queen of Scottish lakes—ruddy coloured, into the river immediately west of Dumbarton Rock after a course of 7½ miles, and on which the town of Dumbarton stands, erstwhile famed for its glass works, but in the present day better and more widely known for

the extensive ship-building and marine engineering works of Messrs. William Denny & Brothers, and Messrs. A. McMillan & Sons.

The Clyde in its course to the sea, unfortunately for its character for salubrity, receives both the domestic and manufacturing sewage of upwards of 1 000 000 inhabitants and the 41 957 000 galls. of water which Glasgow daily uses, 37 193 000 galls. of which are from Loch Katrine, add to its volume.

The Forth and Clyde Canal, 35 miles long, opened in 1790, whose locks admit of the passage of vessels 68 ft. keel, 19 ft. beam, and 8½ ft. draft of water, joins the Clyde at Bowling; and a branch from the canal to the Clyde opposite the mouth of the Cart gives direct communication between the canal and Paisley.

The writer will, in dealing further with the subject, put his remarks under the following heads :

1. History of the Improvement of the River.
2. Progress of the Harbour.
3. Rise and Progress of Ship-building on the River and its Tributaries.
4. Short Description of Other Harbours on the River.

1. History of the Improvement of the River.

In prehistoric times ancient Britons must have paddled their own canoes in its shallow stream, as dugouts have been unearthed, not only on the banks of the river, at Glasgow and at Bowling, but even at the Cross of Glasgow, fully 500 yds. from the present margin of the river; and Roman legions must have encamped on its banks while they were engaged in constructing, under Agricola, A. D. 80–81, a chain of forts between the Clyde near Bowling and the Forth near Bo'ness; and under Antoninus Pius, A. D. 140, in connecting these forts by ramparts of earth and stone, with a deep and wide ditch outside and a paved military road along the inner or south side, to check the inroads of the Caledonian barbarians.

Upwards of 300 years ago—in the summer of 1566—the Magistrates and Town Council of Glasgow made the first attempt on record to improve the river. Detachments of the inhabitants of the City of Glasgow, joined by contingents from Renfrew and Dumbarton, endeavored to open up what the chronicler of that day called "a formidable sandbank" at Dumbuck, about 2 miles above Dumbarton and about

12 miles below Glasgow, at which they laboured for several weeks, residing during the time in timber huts built near the scene of their operations. This attempt must have proved of little value, as Thomas Tucker, one of Cromwell's commissioners, describing Glasgow and the river in a report, dated November 20th, 1656, 90 years thereafter, says:

"The situation of this towne in a plentiful land, and the mercantile genius of the people, are strong signs of her increase and growth were she not chequed and kept under by the shallowness of her river, every day increasing and filling up, soe that noe vessels of any burden can come nearer up than within fourteene miles, where they must unlade and send up theyr timber and Norway Trade in rafts or floates, and all other commodityes by three or foure tonnes at a time in small cobles or boates, in three, four, five, and none above six tonnes a boat."

Nor can much benefit have resulted from the carrying out of the following Minute of Council, dated May 8th, 1740:

"The Council agree that a tryall be made this season of deepening the river below the Broomielaw, and remit to the Magistrates to cause do the same, and go the length of £100 sterling of charges thereupon, and to cause build a flatt-bottomed boat to carry off the sand and chingle from the banks."

Up to 1768 the river between Glasgow and the sea remained practically in a state of nature, choked up with sandbanks, impeded by numerous fords, and only suitable for herring boats and such like craft. Thus the river remained, expanding in useless width as it decreased in depth, until in that year, John Golborne, civil engineer, of Chester, appeared on the scene, and it is to him that Glasgow is indebted for the first really successful step in the improvement of its navigation. By his system of contracting the river by the construction of rubble jetties and the removal of sand and gravel shoals by ploughing, harrowing and dredging, the first marked improvement of the navigation was effected.

In 1773 he took a contract to make Dumbuck Ford 6 ft. deep and 300 ft. wide at low water for £2 300; and in September, 1775, the Town Council, on the recommendation of the merchants, gave him £1 500 for deepening the river 10 ins. more than he was bound to do by his contract, presented him with a silver cup, and gave his son £100. Generous Town Council! Happy engineer!

By an Act of Parliament passed in 1809, the Lord Provost, Magistrates, and Council of Glasgow, under whose control the improvement of the river had up till then been carried on, were constituted Trus-

tees of the Clyde Navigation, and were given power to deepen the river until such time as it was at least 9 ft. deep at high water, neap tides, between Glasgow and the Castle of Dumbarton; and, by an Act passed in 1825, they were authorized to appoint, as trustees, five other persons interested in the trade and navigation of the River and Firth of Clyde, and to deepen the river from Glasgow to Port Glasgow till such time as it was at least 13 ft. in depth.

The constitution of the Trust continued thus until 1858, when it was materially altered by an Act of Parliament passed in that year and still in force, the number of the Trustees being fixed at 25, one being the Lord Provost, nine Town Councilors, and the remaining 15 representatives of the shipping, mercantile and trading interests of Glasgow, of whom two are chosen by the Chamber of Commerce of Glasgow, two by the matriculated members of the Trades House of Glasgow, and nine by ship-owners and rate-payers. The qualifications of the Trustees to be elected by the ship-owners and rate-payers is ownership to the extent of at least 250 tons in any vessel or vessels registered at the Port of Glasgow, or payment of rates to the extent of £25 or upwards per annum; and of electors, ownership to the extent of at least 100 tons, or payment of £10 or upwards of rates per annum.

From 1781 until 1836, the works carried on for the further improvement of the river under the direction consecutively of Golborne, Rennie and Telford, consisted chiefly in the shortening of some, and the lengthening of others, of Golborne's jetties, the construction of additional jetties, the connecting of the outer ends of these jetties by half-tide training walls on both sides of the river so as to confine the water and increase the ebb scour, and the removal of hard shoals by dredging.

It was not till 1836 that the river from Glasgow to Port Glasgow was treated as a whole, and a true appreciation shewn of its future by the Clyde Trustees' then engineer, Logan, in the laying down of river lines, which, with some slight modifications and expansions, have, up till now, formed the limits of the river's improvements.

Parliamentary plans on these lines, approved of by James Walker, Consulting Engineer to the Trustees, were submitted to and sanctioned by Parliament in 1840; but so inadequate was the appreciation of the depth required, that 20 ft. at high water, neap tides, was recommended

by Logan as the extreme depth of the river and harbour, and a clause in the Act empowered the deepening to proceed until every part thereof shall have attained at least a depth of 17 ft. at high water, neap tides.

The depth in the Harbour of Glasgow, and in the river at the present time, is from 27 to 29 ft. at high water, neaps; high water, springs, being about 2 ft. higher. The average tidal range of spring tides at Glasgow is 11 ft. 2 ins., and at Port Glasgow 10 ft., and of neaps at Glasgow 9 ft. 2 ins., and at Port Glasgow 8 ft. 3 ins.

While jetties and training walls, or parallel dikes, performed a useful part in the early improvement of the river, it is to persistent dredging that the enormous increase in the magnitude of the river since 1840 is due.

The early dredging was performed by large rakes, or porcupine ploughs as they were called, because they were provided with strong iron teeth, wrought by hand capstans, which drew the material from the bed of the river on to the banks.

Hand-wrought, and subsequently horse-wrought, dredgers, with small buckets on a ladder, succeeded the plough, and in 1824 the first steam dredger was started on the river. It dredged only to 10 ft. 6 ins. Now, several of the dredgers employed can work in 35 ft. depth of water; and there has been added to the fleet within the last few months the most powerful dredger afloat, which can lift 600 tons of sand from a depth of 40 ft. in one hour by a chain of buckets on a steel ladder, each bucket containing 22 cu. ft.

It is undoubtedly to the application of steam power to dredgers, and the subsequent adoption of steam hopper barges—a French invention—for carrying the dredged material to the sea, that the rapid enlargement, not only of the Clyde and the Harbour of Glasgow, but of the Tyne, the Tees, and several other similar rivers, in recent years is due. But for the introduction of the latter, it would have been physically, financially and otherwise impossible to have disposed, within so limited a time, of the enormous quantities of material which have been dredged from these various rivers and harbours.

Up to 1862 all the material dredged from the River Clyde and Harbour of Glasgow was loaded on punts holding 8 cu. yds., and deposited on the alveus, or foreshores, or the low-lying land adjoining the river. Many acres were thus reclaimed, to the aggrandisement of

the riparian proprietors, to whom the Trustees were required to hand over the ground free of cost.

The adoption and speedy acquisition by the Trustees of steam hopper barges, holding from 240 to 320 cu. yds. each, removed all these obstacles and enabled the deepening, widening, and straightening of the river and harbour to be proceeded with more rapidly, without hampering the Trust's finances, or seriously obstructing the navigation with steam-tugs and trains of punts. The result has been that, while in 1861 the total quantity dredged and deposited on land was 593 176 cu. yds., the total quantity dredged in 1892 was 1 598 984 cu. yds., only 65 752 cu. yds. of which were deposited on land. The total quantity dredged during the last 48 years amounts to 39 511 418 cu. yds. To enable the material dredged in the deepening of the river to be more economically disposed of, two twin-screw barges, each of 1 000 tons hopper capacity, were added simultaneously with the new dredger.

The best thanks of river and harbour authorities, such as the Clyde Trust, of River and Harbour Engineers, and of the community at large, are justly due to those marine engineers and ship-builders who have made dredging plant a specialty, among whom the firms of Messrs. William Simons & Co. and Lobnitz & Co., Renfrew, and Fleming & Ferguson, Paisley, occupy deservedly prominent positions.

In 1755 the Clyde at Glasgow was only 15 ins. deep at low water, and 3 ft. 8 ins. at high water, while the depth at Marlinford, 3 miles below the harbour, was 18 ins. and at Erskine, or Kilpatrick Sands, about 8 miles below and at Dumbuck Ford 10 miles below, only 2 ft. at low water.

In 1781 the depth at Dumbuck Ford was 14 ft. at low water ; it is now 20 feet.

In 1806 Telford reports that on February 14th of that year the *Harmony*, of Liverpool, came up with the ordinary spring tide, drawing 8 ft. 6 ins of water; but up to 1812 the river, from the harbour downwards to Bowling, was so shallow that it was necessary for the *Comet* to leave Glasgow and Greenock respectively at or near high water, to prevent grounding in the river.

An old gentleman, who had been connected with the Clyde navigation for upwards of 50 years, informed the author a few years ago that he made a voyage in the *Comet* in 1812, leaving Greenock at 10 A. M. for Glasgow. It was 2 P. M. before they got to Bowling, 10½ miles above

Greenock, in consequence of a ripple of a head wind, and from there all the passengers had to walk to Glasgow owing to the lack of water, the tide having ebbed. As late as 1815, a traveler by that steamer records the fact that he left Glasgow in the morning and arrived at Greenock after a seven-hours' passage, three hours of which were spent lying on a sand-bank at Erskine. Lighters not drawing more than 4½ ft. have been known, owing to neap tides and consequent groundings, to take six weeks to make the voyage from Greenock to Glasgow and back; and while all but two of the first 20 steamers built on the Clyde had their engines made by Glasgow engineers—the engines of the excepted two being made by Boulton, Watt & Co., Soho—their hulls were built at Dumbarton, Port Glasgow and Greenock.

Flyboats for passengers, with sails and oars, were used before the introduction of steamboats, a whole day being spent frequently in the passage between Glasgow and Greenock. Steam-tugs for towing the lighters followed soon after the introduction of passenger steamers, and in recent years steam has been extensively applied to the lighters themselves.

Before the year 1818 none of the vessels in the foreign trade came further up the river than Greenock or Port Glasgow. Their cargoes were there discharged into lighters, which carried them to Glasgow, and at that date the largest ship belonging to either Port Glasgow or Greenock did not exceed 400 tons. In 1821, vessels drawing 13½ ft.; in 1830, drawing 14 ft.; in 1840, 17 ft.; in 1850, 19 ft.; in 1870, 21 ft.; in 1880, 23 ft.; and in 1892, 26 ft. 5 ins., came up the river; while steamers with a draft of from 23 to 24½ ft. now pass up and down the river almost daily, leaving Glasgow and Greenock respectively about an hour or so before high water, and passing over the navigation between these points in two hours.

The river, cross-channel and other steamers, of 16-ft. draft and under, leave Glasgow and Greenock respectively at any state of the tide. The towing of sailing vessels between Glasgow and Greenock by steam-tugs is now nearly universal. Small sailing craft are formed into trains, and each train is towed by one tug. Deep-drafted sailing vessels and the large transatlantic and other foreign-going steamers have a tug each to take them round the quick bends, and the largest class have generally a tug ahead and a tug astern.

The bed of the river from Glasgow to Port Glasgow is now virtually

level throughout, and 7½ ft. of the 9½ ft. increased range of tide in Glasgow Harbour, and the whole present depth of from 16 to 20 ft., at low water, spring tides—together 23½ to 27½ ft.—has been obtained by dredging out the bottom of the river.

As may be readily supposed, groundings in the river were of frequent occurrence in the earlier days of the river's improvement, shipowners being prone to load their vessels to the utmost capacity of the deepened river, making too little allowance for tides nipped by frost or east winds. But at length the deepening has got the better of the deep loading, so that, while in 1871, 59 vessels grounded between Glasgow and deep water at Greenock—two of them below the Clyde Trustees' western boundary, the registered tonnage of the largest of which was 2 069 tons, and the greatest draft 21 ft. 7 ins.—in 1892 only nine vessels grounded, the registered tonnage of the largest being 3 613 tons, and the draft 26 ft. 5 ins.

In 1800 the time of high water at Glasgow was two hours behind Port Glasgow; now it is only one hour. Even as late as the summer of 1858, a float put into the river at Glasgow Bridge, at the first of ebb, took 537 hours, or 43½ tides, to reach Port Glasgow, a distance of 19.4 miles; while in the summer of 1881, a float, under exactly similar conditions, reached Fort Matilda, below Greenock, a distance of 23.5 miles, in 86 hours 20 minutes, or seven tides.

Any history of the improvement of the river would be incomplete if reference were not made to the removal of Elderslie Rock, a huge vein of trap which extends across the river a short distance above Renfrew. In the early report of the condition of the Clyde, no mention is made of this rock, but the Blawarthill Sand—one of the many shallow fords on the river—was situated where the rock was subsequently found, and in 1755 there was a depth on this sand of only 18 ins. at low water, and 4 ft. 9 ins. at high water. It was not till 1854 that its existence was discovered by the grounding on it of the *Glasgow*, one of the first steamers trading between Glasgow and New York, which, while passing up the river, struck upon it and knocked a hole in her bottom. It was at first thought that it might be a large boulder that had done the damage; but borings showed that it was rock, that it extended over an area of the bed of the river 925 ft. in length by 320 ft. in breadth, and that it was a hard whinstone or trap dike.

From the time of its discovery till the beginning of 1869, boring

from a movable stage and by diving bell, and blasting with gunpowder, at an expenditure of £16 000, had given a minimum depth at low-water springs of 14 ft. for half the width of the channel, and a minimum depth of 8 ft. for the other half, the total width of the river there, from bank to bank, being only 410 ft. It was not till 1880 that the removal of the rock, so as to give a uniform depth of 20 ft. at low-water springs, over every portion of the channel, was commenced by Colonel Beaumont with his diamond drills. In addition to the novelty of using diamond drills, there was the further novelty that the holes were bored, charged and exploded from a floating barge without the aid of divers, a mode of blasting subaqueous rock which had never before been adopted.

The boring was done in longitudinal belts, in sections 40 ft. long. The holes were located in five rows, 2½ ft. apart transversely, and 5 ft. apart longitudinally, so that the holes in alternate rows would be opposite one another. Eight holes longitudinally were bored simultaneously, then charged and blasted, and the other four rows dealt with in the same way. When all the five rows in the section had been bored, charged and blasted, the boring barge was shifted up stream and operations commenced on the next 40-ft. long section, and an ordinary, but powerful, single ladder, small bucket dredger following, lifted the broken rock, and left an open face for the next belt of holes.

It was early found that where the depth of hole was more than 10 ft., the rock was not sufficiently disintegrated to enable the dredger to clear it freely away to the bottom of the holes, and the deeper portions of the rock were therefore taken in two depths, or breaks, the first depth being bored to 17 ft. at low water, blasted and dredged.

The longitudinal belts of holes were continued from the south side outward to the middle of the river, until the whole ground in the southern half was cleared away to 20 ft. at low water, the whole up-and-down traffic being meantime confined to the north half of the river. The whole traffic was then diverted from the north into the new south channel, which was marked by three of Pintsch's compressed gas-lit buoys, capable of burning three months continuously. The operations were then continued northward until the whole depth of the river-bed was cleared to 20 ft.

The explosives used were dynamite, blasting gelatine, tonite and potentite. Dynamite was found most satisfactory. Blasting gelatine

proved the most powerful explosive, but, when frozen, was more dangerous to handle and more difficult to explode thoroughly. Tonite and potentite were found to be less powerful than dynamite, and failed to explode unless kept quite dry.

Two horizontal engines on the deck of the boring barge, supplied with steam from two boilers, drove the eight drills by a main shaft, which extended the whole length of the barge. The diamond boring tool was a steel annular ring, $2\frac{1}{4}$ ins. diameter and $\frac{1}{2}$ in. hick, studded with diamonds overlapping one another. This annular ring or crown was screwed on to the bottom of the boring rod, which, in suitable lengths, was carried inside an iron guide tube extending down to the bottom of the river-bed; the rod was connected at the top to a drill bar suspended from an iron diagonal framework on the barge. Rotary motion was given to the drills by means of phosphor bronze bevel wheels, working in a frame and driven from the main shaft on deck by an ingenious arrangement of ropes and loose pulleys which allowed for any lateral or vertical movement of the drill caused by rough weather, the rise and fall of the tide, and the ranging of the barge through the suction of passing steamers. The drill bar was driven at the rate of 400 revolutions per minute; and during the whole time that the boring was proceeding, water, at a pressure of 40 lbs. per square inch, was forced down through the hollow boring rod, to wash out the detritus and keep the face of the diamond crown cool. The pressure on the drill was applied by means of counterbalance weights, varied according to the hardness of the rock bored. In the hard blue whinstone, the boring of the holes of $2\frac{1}{4}$ ins. diameter proceeded at the rate of 2 ft. per hour, and 5 ft. per hour in softer stone.

When the necessary depth of hole was bored, which was ascertained by sounding the hole and comparing the depth with that on the tide gauge adjoining the works, the drill rods were withdrawn, and the dynamite charges lowered through the guide tubes into the bottom of the holes and the tubes withdrawn. The dynamite charges were fitted with detonators and primers, and attached to each charge were electric cables, which were led up to the surface of the water. All the charges were then connected, and the shot-hole wires at either end were attached to a main cable, which was carried to the positive and negative poles of a Siemen's high-tension electric

exploder. The barge was then withdrawn about 60 ft. from the place of the explosion, and the row of eight holes was fired simultaneously, resulting in the displacement of something like 100 tons of rock, the only disturbance being a slight upheaval of water. The greatest amount lifted by the dredger in one day was 280 tons. A diving bell afterwards went over the ground and removed any large stones that had been left by the dredger.

More readily to convey an idea of the amount of labor involved in the removal of the rock, it may be stated that something like 16 000 holes were bored, equal to about 90 000 lin. ft. About 110 000 tons of whinstone and boulder clay were dredged. About 76 000 lbs. of dynamite and other explosives were used without loss of life or damage to limb, and were exploded by means of about 35 miles of electric cable and shot-hole wire. The cost from first to last was £70 000. Operations were carried on in all weathers, fair and foul, without interfering in any way with the continuous day and night traffic of the river; this, during the fully five years over which the work extended, was confined to the one or other half of the channel, and amounted to 180 000 vessels with a tonnage of 33 000 000 tons, and included the largest steamers then afloat, such as the *City of Rome*, the *Etruria*, and the Russian ironclad, *Peter the Great*.

The dredging plant of the Clyde Trustees consists of five steam dredgers, from 40 to 90 H. P. nominal (the latest addition, already referred to, being a steel hull, single traversing ladder, twin-screw propelled, electric-lighted dredger, 200 ft. long by 37 ft. broad by 12½ ft. deep, with a mean draft of 8 ft., cutting its own floatation); one tug steamer, two diving bells, one of them wrought entirely by steam; one floating steam 10-ton digger, and 18 steam hopper barges from 35 to 160 H. P. nominal. The latest two of the barges, also previously mentioned, have steel hulls, twin screws driven by triple-expansion engines, are each 200 ft. long by 34 ft. broad and 15½ ft. deep, and have a mean draft of 12½ ft. and a speed of 10 knots per hour when loaded.

The lighting of the channel of the Clyde between Glasgow and Port Glasgow is by three light-towers, at Dalmuir, Rashilee, and Donald's Quay, respectively, all above Bowling; by a beacon light at Longhaugh Point, one mile below Bowling, and by Dumbuck Lighthouse, about two miles below Bowling; by Garmoyle Lightship, one

mile below Dumbarton Castle; by Cardross Light, one mile above the Clyde Trustees' boundary at Port Glasgow; and by seven lighted buoys on the south side of the channel, between Dumbarton and Port Glasgow, the whole being lit by Pintsch's gas. The Clyde from Port Glasgow to the sea is lighted by the Clyde Lighthouses' Trust, under whose care the Estuary is to the Cumbrae Heads, 22 miles below Greenock.

In 1867 the Trustees erected works on the north bank of the river at Dalmuir, 8 miles below Glasgow, embracing slipway, engine and boiler works, for the prompt and efficient repair of their ever-increasing dredging and other floating plant.

2. Progress of the Harbour.

Three hundred years ago it could not have entered into the mind of the most sanguine and far-seeing citizen of Glasgow that this city, founded by St. Kentigern or St. Mungo, in A. D. 560, would ever become one of the leading ports of Great Britain; situated as it was on a shallow, sand-choked stream, upwards of 20 miles from deep water at Greenock, and its usual port, Irvine, in Ayrshire, 29½ miles by land from Glasgow, from which merchandise was conveyed to and fro by lighters and pack horses.

The magistrates of Glasgow, however, with that doggedness characteristic of Scotchmen, determined to have a port nearer home, and in 1658 made overtures to the magistrates of Dumbarton to purchase ground for an extensive harbour there; but these were declined on the ground that the great influx of mariners and others would raise the price of provisions on the inhabitants; they therefore, in 1662, purchased 13 acres at Newark, on which they afterwards laid out the town of Port Glasgow, built harbours, and constructed from the design of James Watt the first graving dock in Scotland, recently enlarged.

While thus fostering Port Glasgow, they still hankered after accommodation for ships at Glasgow, and in 1688 built a quay at the Broomielaw there at the cost of £1 666 13s. 4d.

In 1755 Smeaton recommended that in order to secure 4½ ft. of water at all times up to this quay, a dam be put across the river four miles below Glasgow with a lock 18 ft. in the clear, to take in a vessel 70 ft. long, or to let pass a sloop or brig of above 100 tons when there was water in the river to admit it.

The extension of the harbour synchronized with the deepening of the river, so that, while in 1800 the quayage was only 382 yds. long, and the water area of the harbour only four acres, the length of the quayage is now 11 056⅓ yds., or 6 miles 496⅓ yds., and the water area 160½ acres; fully one-half of the latter and of the total quayage having been added since the author became engineer to the Trustees.

The extension was from Glasgow Bridge downwards. Until 1865 the sides of the river afforded sufficient ground for the extension of the quayage. The first dock, called Kingston Dock, having 5⅓ acres of water space and 830 lin. yds. of quayage, was opened in 1867. The second dock, by special permission of Her Majesty, named the Queen's Dock, having 33¾ acres of water area and 3 334 yds. of quayage, with 20 ft. depth of water in front at low tide—spring tides—was opened in 1880. Both docks are tidal; and a third tidal dock which will be briefly described later on is in progress.

The early quays of the harbour were of stone, founded not much under the level of low water. Subsequently, as the deepening of the river progressed, bearing and sheet piling of round home timber were introduced, followed, as the deepening went on, by wooden wharfing of squared red pine timber, and quay walls carried on red pine bearing piles and sheet piles.

The deepening of the harbour and the lowering of low-water level, especially within the last 20 years, has injuriously affected the foundations of the quay walls, built even as late as 35 years ago; but by close sheeting in front of the walls, with creosoted pitch pine piles varying in length from 30 to 45 ft. by 12 ins. thick, driven in bays of three and four piles each and tied back at intervals with 2¼-in. tie rods to heavy blocks of concrete masonry—the walls, built 70 and more years ago, have been kept up and made as suitable for the vessels of to-day as they were for the vessels of the period at which they were erected.

In 1870 the author, to meet the increasing depth demanded by the ships frequenting the port, and to secure a permanency which quay walls on bearing and sheet piles did not afford, adopted for the substructure of the quay walls a system of single brick cylinders 12-ft. external diameter, tongued and grooved into each other, filled with concrete, and of brick coped with granite for the superstructure; followed two years afterwards by triple groups of Portland cement concrete cylinders, 9 ft. external diameter, filled with concrete for the

substructure, and for the superstructure concrete rubble faced with dressed freestone ashlar and coped with granite. In recent years he has altered the facing of such walls to concrete ashlar.

As the details of this form of structure may be new to American engineers, the author will give a short description of the Queen's Dock just referred to.

The plan of the harbour, which accompanies this paper, shews the dock, which comprises three basins—the north basin, 1 866 ft. long by 270 ft. wide; the south basin, 1 647 ft. long by 230 ft. wide, with a quay between them, 195 ft. broad; and an outer basin, 695 ft. wide at its widest part by 1 000 ft. long. As already stated, the dock is tidal and is approached by an entrance 100 ft. wide, which is crossed by a swing bridge constructed by Sir William Armstrong & Co.

There are four coaling cranes to lift 20 tons each on the north quay of dock, all of which, together with the swing bridge—which is designed to carry 60 tons of a rolling load on any part of its roadway—are wrought by hydraulic power.

Before proceeding with the construction of the dock, it was necessary to learn by boring the character of the ground in which the walls were to be placed. One hundred and twenty-three borings were made for this purpose along the lines of the quay walls, and it was ascertained that the material, except along a portion of the north wall, where rock was sufficiently near the surface, and at the northwest corner, where boulder clay was found, was the worst possible in which to construct in the usual manner such works, consisting, as it does, of water-bearing gravel and sand, interspersed with pockets of mud.

Owing to the enormous quantity of water, the walls could not be constructed at a reasonable cost by excavating trenches to the required depth, except where the rock was sufficiently near the surface, or in boulder clay. The north quay wall of the dock, so far as founded on boulder clay, and that is for about 1 297 ft. of its whole length of 2 951 ft., is of the usual description, the only difference being that concrete founds, 2 ft. 6 ins. thick, were used in place of freestone blocks; and rubble set in Portland cement, a much superior mode of construction, was employed for the backing, instead of rubble built with ordinary mortar. Where the bottom consisted of strong coarse gravel or rock, liquid concrete was substituted for the solid concrete founds, by which means all the hollows in the surface of the rock were thoroughly

filled and an even and fair surface obtained on which to commence the building of the wall.

For all the other walls, except at two or three places where pockets of clay were encountered and piling was used and for the seat for the swing bridge, concrete cylinders were adopted for the substructure.

The cylinders carrying the quay walls are triple. They were made in rings, 2 ft. 6 ins. deep by 1 ft. 11 ins. thick, in movable wooden moulds on a platform. The concrete consisted of 5 of gravel, or broken stones and sharp sand, to 1 of Portland cement of the strongest description, mixed together by steam-power in a mixer designed for the purpose, water being added to bring the mass to a plastic state. To facilitate lifting, the rings were divided into three and four pieces alternately, so as to break bond when built into the cylinders. The dividing of the rings was very simply effected; malleable iron division plates $\frac{3}{8}$ in. thick were placed across the wooden moulds in the positions required before the concrete was filled into them; the concrete was then put in and well punned with rammers weighing 25 lbs., so as to secure homogeneity and a smooth surface. Twelve hours afterwards the division plates were withdrawn, and two days thereafter the wooden moulds; and in periods varying from nine days in the hot weather of summer to three weeks in the rains of winter, the rings were ready for removal and building. The contents of one ring complete were $10\frac{1}{2}$ cu. yds., and the weight 18 tons, the heaviest portion weighing about 6 tons.

The cylinders were each 11 rings, or 27 ft. 6 ins. in height; the bottom ring, differing from the others, was called a "corbelled" ring, because it was made less in thickness at the bottom to fit into a cast-iron shoe, and tapered inwards to the full thickness of 1 ft. 11 ins. The shoe was 2 ft. deep of 1-in. metal, and of the same external size and shape as the rings, the underside of the bottom ring resting on a shelf in the shoe 6 ins. below the top edge of the shoe. This shelf was formed of an inner ring of cast iron 1 in. thick, projecting at the top 12 ins. inwards from the inside of the outer side of the shoe, and tapering outwards to the bottom of the shoe, where it joined the outer ring, thus forming a cutting edge to the shoe, the wedge-shaped space between the outer and inner ring being filled with concrete.

The shoe is only under the outward circumference of the "corbelled" ring, the inner parts of the ring being unshod. The shoe

weighed about 4 tons 10 cwts., and for convenience in placing in the trench was made in six parts and bolted together.

In proceeding with the construction of the substructure, a trench was cut on the line of the quay wall; the bottom of the trench was about 12 ins. below low-water level, where it was made 21 ft. wide, the sides sloping upwards with a batter of $1\frac{1}{2}$ horizontal to 1 perpendicular, and the necessary staging was erected to carry the traveling cranes and digging apparatus. On the bottom of this trench the shoes were placed exactly in the line of the quay wall, and the space between the outer and inner rings of the shoe was filled up with concrete, as already explained. The "corbelled" ring was placed on the shelf in the shoe, and bolted to it by 13 $1\frac{1}{4}$-in. bolts, a malleable iron ring 5 ins. by $\frac{1}{2}$ in. thick being sunk into the "corbelled" ring on the top, the places for this ring, and for the bolts passing through the concrete ring, having been made in the moulding of the latter. The remaining 10 rings, forming a triple group of cylinders, were set, one on top of the other, in Portland cement, in three and four pieces alternately. The cylinders were placed in the trench so as to dovetail into each other, one cylinder in front and two behind, and two in front and one behind, alternately. The sides of the groups, where they pressed against each other, were flattened for a length of 5 ft., so as to ensure a good bearing.

When the building-up of the rings forming a group of cylinders was completed, the sand and gravel were dug out simultaneously from within each of the three cylinders by means of excavators specially designed for the purpose. From 300 to 450 tons of cast-iron weights, of the same shape as the rings, were generally required to force each group of cylinders down the required depth of 48 ft. 6 ins. below the cope level of quay, the tops of the cylinders finishing 9 ins. below low-water level. The average rate of sinking was about 12 ins. per hour. In good working sand as much as 3 ft. per hour was, however, attained. When the group had been sunk, it was cleaned out by means of the excavators to the level of the bottom of the shoe, and each cylinder was then filled to the top with Portland cement concrete, and on this foundation the quay wall is built.

The walls are of concrete rubble, many of the stones weighing from 2 to 3 tons each, and faced with freestone ashlar in courses ranging from 18 to 15 ins. in thickness, the stones being not less than

4 ft. long by 2 ft. broad on the beds, and the headers not more than 10 ft. apart, centers. The cope is of granite, 3 ft. 6 ins. broad by 17 ins. thick, in lengths of not less than 4 ft.; and the mooring paals, or bollards, which are 32 ft. apart, centers, are built into the wall immediately behind the cope.

The swing bridge across the entrance to the dock rests on a foundation probably unique in the annals of swing bridges, viz., on a group of concrete cylinders, 12 in number, each 9 ft. in external diameter, 29 ft. in depth by 23 ins. thick, resting on cast-iron shoes, similar to those described for the quay-wall foundations. The cylinders were sunk in the manner already described, and after they and the interstices between them were properly cleaned out, all the voids were filled to the top with concrete, chock piles being driven where required. On the center of the rectangular area, 36 ft. 4 ins. by 27 ft. 3 ins. by 29 ft. deep, thus formed, a stepped ashlar pier 16 ft. square at the bottom and 10 ft. square at the top by 7 ft. high was erected, which carries a block of granite 7 ft. square by 3 ft. 6 ins. deep, on which the center lifting press rests. The pier is surrounded by concrete rubble, the whole forming a mass of masonry 36 ft. 6 ins. by 32 ft. 6 ins. by 10 ft. 6 ins. high, to the level of the floor of the bridge press chamber. The center pier sustains a weight of 800 tons.

Considerable difficulty was experienced in securing stable foundations for the hydraulic rams for working the bridge and for the capstans and side walls of the bridge pit, the ground being loose and insecure where these had to be placed. Single concrete cylinders placed apart, and spanned between by brick arches, overcame the difficulty.

The bridge is 181 ft. 6 ins. long by 40 ft. 6 ins. wide, the length overhanging the center of the center press and partly spanning the 100-ft. opening being 126 ft. 6 ins.

The swing bridge and hydraulic machinery have been in daily use since September 18th, 1877, when the dock was formally opened by the admission into it of the Anchor Line Steamship *Victoria*, 369½ ft. long by 40 ft. broad, 2 081 tons register.

The coaling cranes are capable of lifting 20 tons. They are placed on stone seats, the granite tops of which are 8 ft. above the level of the quay, and 21 ft. 6 ins. square; the lifting chains have a sweep of 29 ft. 9 ins., and, when at right angles to the face of the quay, project 19 ft. 9 ins. beyond the water face of seat; the lifts of the chains are 20 ft.

In addition to their employment in the shipment of coals, they are also adapted to the loading and unloading of machinery to their maximum lifting power.

The sheds are 60 ft. wide by 15 ft. high to the underside of the run-beams, and 27 ft. to the ridge of the roof; the back walls are of brick, 19 ins. thick, with freestone base course, cope and door openings; the roofs are of iron, and the fronts are closed their entire length, with sliding gates of timber. The cost per linear foot of shed at present prices is £10 10s.

The cost of the quay walls per linear yard including the excavation for trench below level of cope, was:

	£	s.	d.
Let in August, 1872:			
Quay walls on cylinders	154	2	0
Quay wall on sheet and bearing piles	144	8	0
Ordinary quay wall founded on boulder clay	116	5	0
Quay walls on piles and concrete, substituted for cylinders	172	0	0
Let in April, 1876:			
Quay wall founded on boulder clay	101	7	6
Quay wall on cylinders	139	4	0
Let in November, 1876:			
Quay walls on cylinders	129	12	8
" founded on rock	101	6	8

The total cost of the dock when fully equipped was £825 000, exclusive of land.

The following particulars connected with the dock may possibly be of some interest:

Excavation for walls above formation level	255 871	cu. yds.
Excavation in wall trenches	494 764	"
Excavation in sinking cylinders	126 407	"
Concrete in cylinder rings	1 800 203	cu. ft.
Concrete in filling of cylinders	1 313 010	"
Gravel filling of cylinders	99 495	"

Number of cylinders—triple	607
" twin	1
" single	20
Total	628

Total length of cylinders, 17 085 ft., or 3 miles 415 yds.

Ashlar masonry	747 223	cu. ft.
Rubble and concrete masonry	2 511 919	"

The quay walls are founded as follows:

Upon concrete cylinders	2 813	lin. yds.
Upon boulder clay	479⅔	"
Upon rock	210⅓	"
Upon hard gravel	122	"
Partly upon rock and partly upon boulder clay overlying rock	12½	"
Upon timber piling and concrete	56½	"
Timber wharf at entrance	134	"
Total	3 828	"

or 2 miles 308 yds.

The total quantity dredged in connection with the formation of the dock was 2 855 000 cu. yds.

The first of the ground acquired for the dock was bought in 1843 at 6s. 6d. per square yard, and the last in 1872 at 35s. Since the latter date, ground in the immediate vicinity, but not so favorably situated, has changed hands at 65s. per square yard.

The demands still continuing for increased quay accommodation, notwithstanding the large addition made to the harbour by the construction of the Queen's Dock, the Trustees nine years ago got powers from Parliament to construct another dock on the south side of the river. This is shown on the plan of the harbour already referred to, and comprises a canting basin and three berthing basins.

The entrance is completed, and the north basin nearly so, and a two-story shed, 70 ft. wide, is being erected on the north quay of that basin. The depth of the canting basin is to be 28 ft., of the north basin 20 ft., and of the center and south basins 25 ft. at low water, spring tides.

The substructure of the quay walls consists of a row of 9-ft. diameter triple concrete cylinders, except the walls of canting basin, which, in consequence of the additional depth of that basin, have a single row of 9-ft. diameter twin cylinders behind the row of triple cylinders, and the superstructure of all the walls consists of concrete rubble faced with concrete ashlar.

The thickness of the superstructure of the walls of the north basin, and of the center basin so far as constructed, is 16 ft. at bottom (on the top of the cylinders), and 6 ft. 6 ins. at top. Those of the canting basins are 26 ft. at bottom and 9 ft. 6 ins. at top. All are tied back at from 50 to 70 ft. intervals by 2½-in. tie rods to blocks of concrete masonry 12 ft. long by 8 ft. deep by 6 ft. thick. The whole of the work is being executed administratively, that is, without the aid of contractors, the iron shoes, all stones, including dressed granite cope, and other granite work ready for building, cement, timber, etc., being contracted for.

The cost of the walls of north basin was £80 per linear yard; of the walls of center basin, so far as constructed, £90 per linear yard; and of the walls of canting basin, so far as constructed, £120 per linear yard.

To enable the dock works to be gone on with, the Renfrew Road, the only thoroughfare between Glasgow and the great ship-building center of Govan and the Burgh of Renfrew, 60 ft. wide, had to be diverted for 1 575 lin. yds., and a new system of main sewers laid down for the populous district which surrounds the docks.

The river side and dock quays are well equipped with everything necessary for the speedy loading and unloading of vessels, including 5¾ miles of harbour railway on the north side, and 3 miles on the south side, connecting with the whole railway system of the Kingdom.

The Clyde Trustees have no warehouses, but have 30 acres of sheds for the accommodation and protection of goods. Unlike dock companies, the Trustees do not load and unload goods; these duties, with their consequent profits, are left to the ship-owners to perform. They, however, by means of 42 steam and hydraulic cranes ranging in lifting power from 30 cwt. to 75 tons, load coals and heavy machinery, discharge ore, mast vessels, and place boilers and engines on board steamers built on the river banks and in the neighbourhood; and there is now in course of erection in the harbour to meet the ever-increasing weight of marine boilers, a pillar crane, to be tested to 150 tons, of the following character and leading dimensions: the weights to be raised with a steel wire rope to a height of 60 ft. above the top of the crane seat from a depth of 20 ft. below the quay level, or a total lift of 100 ft. Its radius or sweep to be 65 ft., and to project 45 ft. beyond the face of the seat. The jib, a double steel tube, well braced, to be 90 ft. long, and 3 ft. 3 ins. in diameter at the center of each tube. Its weight, including stays, will be 45 tons.

The diameter of rope drum, 5 ft. 2 ins.; length, 10 ft.; weight, 10½ tons. Diameter of cast-steel roller path, 33 ft.; weight, 12 tons. In the live roller ring, 75 cast-steel rollers of a maximum diameter of 14 ins., weighing in all 10½ tons.

The washer plates for holding-down bolts, six in number, to be 6 ft. square, and their total weight 13 tons. The six holding-down bolts to be each 38¾ ft. in length by 5 ins. in diameter, and weigh 8 tons.

The steel center pillar to be 17 ins. in diameter, and the weight, 6 tons. The crane-framing to be 27½ ft. in height, and to weigh 50 tons, and the boiler to be 14 ft. high by 6 ft. in diameter, and to weigh 6 tons. The crane to have two separate lifts, 130 and 20 tons. The steel-wire rope for the former lift to be 2½ ins. in diameter, and 1 100 ft. long; and for the 20-ton lift, 1¼ in. in diameter and 370 ft. long. The main block with four pulleys to be 12 × 7 × 3 ft., and to weigh about 6 tons. The crane will be balanced by 100 tons of iron and steel punchings in a ballast-box.

There are to be two speeds for heavy lifts, 2 ft. per minute for 130 tons, and 4½ ft. per minute for 60 tons; and a separate engine for two speeds for loads up to 20 tons, viz., 12 ft. per minute for 20 tons, and 30 ft. per minute for 8 tons. The revolving to be performed by a separate engine with two speeds—a revolution in 6 minutes for 130 tons, and 3¼ minutes for 60 tons.

A description of the seat on which the crane is being erected may be of interest. Its site is shown on the plan on Finnieston Quay, north side of harbour.

To admit of its erection, a portion of the quay wall forming the north line of the river had to be taken down before proceeding with the substructure. This consists of three front groups of triple concrete cylinders, with four single concrete cylinders close behind them, and three groups of triple concrete cylinders close behind the latter, all of 9 ft. external and 5 ft. 9½ ins. internal diameter, resting on cast-iron shoes. The front groups were sunk to the average depth of 60 ft. 8 ins., the four single cylinders to 59 ft., and the three back groups to 56½ ft., below the level of cope of quay wall, and all filled with Portland cement concrete. The tops of the front cylinders are 25 ft., and the single and back cylinders 22½ ft., below the level of cope of quay wall; and from these levels the superstructure of the seat, which is 40 ft. square, rises to 20 ft. above the cope level of quay wall, and consists

of concrete rubble hearting with granite corners and cope, faced in front to the level of the underside of cope of the quay wall with redressed freestone ashlar. This ashlar was from the portion of the quay wall removed to permit of the erection of seat. The superstructure at back and sides to the level of the quay was faced with heavy rubble, and thence to the underside of the cope of seat with concrete ashlar.

Several of the largest ship-builders and marine engineers, such as Messrs. A. & J. Inglis, the Fairfield Ship-building & Engineering Company, Limited; Alexander Stephen & Sons, and James & George Thomson, put boilers, engines, etc., on board by means of shears or cranes in their own yards.

Berths are set aside for special trades, such as coal, lime, timber, river passenger steamers and cattle, and fully a half of the total quayage of 11 056¼ yds. is allocated to the leading lines of steamers trading to outports of Scotland, England and Ireland, to the leading Continental ports of Europe, to the British Colonies, and to America, Canada, the East and West Indies, Africa, etc.

The Trustees permit ship-owners having allocated berths to place steam cranes on the breasts of the quays, and there are at present 32 of these in use, ranging from 30 cwts. to 30 tons in lifting power.

In 1856 a private ship-building firm on the confines of the harbour built a graving dock 500 ft. long in connection with their yard, and it was not until 1875 that the first public graving dock, 565 ft. long by 22 ft. 10 ins. on the sill at high water, spring tides, was completed by the Clyde Trustees at a cost, exclusive of land, of £134 800. Another, 575 ft. long by 52 ft. 4 ins. wide at bottom, 92 ft. wide at top, with the same depth on the sill as the last named, constructed by and from the designs of the author without the aid of contractors, as has been all the quayage of the harbour for the last 10 years, was opened in 1886 at a cost, exclusive of land, of £108 200.

The wing walls and apron of the latter are carried on triple concrete cylinders, 9 ft. diameter, sunk 24 ft. into the ground and filled with concrete, their tops being 3 ft. below the level of top of sill at the entrance. One of these triple cylinders was used as a well for a 13-in. centrifugal pump, which was required to keep under the large amount of water flowing from the gravel strata in which the excavation for the dock had to be carried.

Into this well were led three lines of 9-in. open-jointed, spigot and

faucet pipes; these were of cast iron under the sills, and fire clay thence to the upper end of the dock. These pipes were laid under the foundations of the floor on an inclination of about 1 in 300, with branches from each as required, to give free passage to every spring of water that was met with. To prevent them from choking with sand, a small wire rope with wire brush attached was carried through each pipe from the well to the upper end, as the work of excavation proceeded from the entrance to the head of dock, and they were quite successfully cleared by this means.

The pipes were bedded in, and covered to the depth of 18 ins. with clean riddled gravel, which kept the ground well dried for the laying of the bottom bed of concrete forming the lowest section of the foundations of floor and side walls. On this concrete bed, which is 12 ins. thick at the center, and 3 ft. 2 ins. at the sides, a brick-in-cement invert 4 ft. 2 ins. thick was laid to the radius of 120 ft., surmounted by a bed of concrete 4 ft. 5 ins. thick in the center, tailing out to 12 ins. on each side with a camber of 6 ins. on the upper surface. On this was laid the flooring of the dock consisting of nidged granite blocks 6 ins. thick, set in and grouted with cement. The floor at the center is 12 ins. below the sill, and is level longitudinally.

The limited width of the site of the dock prevented the excavation being taken out to the usual width on the top, and the desire to get the dock as wide and long as the ground would admit of necessitated the driving, along both sides and round the head, of pitch pine sheet piling, 28 ft. long by 9 ins. thick on the sides, and 12 ins. thick round the head of dock, in four-pile bays, with slip tongues, 16 ft. of the length being into the undisturbed bottom.

In front of this sheet piling, brickwork was carried up from the invert over the top of the piling, and the ground behind the piling was cut away for a breadth of 7 ft. 6 ins. and a depth of 6 ft. and filled with concrete, on which the outer side walls, 37 ins. thick at bottom and 18 ins. at top, plumb at back and stepped inside, were built, the whole being carefully pointed outside to secure water-tightness.

Inside of these walls, the whole body of the dock is of concrete, except the side walls of the entrance, the stairs, timber slides, the top altar course and cope, which are of granite. All the other altar courses, 17 in number, are of granolithic, 14 ins. on the tread and 18½ ins. rise, except the bottom course, which is 30 ins. average rise.

The concrete of the sides of the dock was put in between movable frames, roughly stepped to receive the granolithic altar courses, which were moulded on a platform on the working ground, and when thoroughly dry, built in position like ashlar, except the bottom altar course, which was made *in situ* in 8-ft. lengths and in alternate blocks, to allow of setting and shrinkage.

The floor of the caisson chamber is a brick-in-cement invert, with granite stones and cast-iron blocks alternately, for carrying the rails upon which the caisson travels, the cast-iron blocks being cored out for the drainage of the mud from the rails.

The side and end walls of the chamber are of brick, with rectangular voids filled with concrete, and having a freestone string course on each side for the hauling-chain path.

The caisson chamber is covered over with Lindsay's patent steel trough decking, having the troughs filled up with concrete, and a layer of 4 ins. thick over the whole, and causewayed over to form a part of the roadway.

The semi-circular head of the dock is formed of brick in cement, stepped at back, with rectangular voids filled with concrete and faced with moulded granolithic-faced concrete ashlar, battered on the face to 1 in. per foot, in courses 18 ins. deep, chamfered on top and bottom edges, the stretchers being 4 ft. long by 1 ft. 9 ins. broad on bed, and the headers 3 ft. 6 ins. long by 2 ft. broad.

There are two stairs with two stair approaches to each, and four timber slides on each side of the dock. The stairs are 4 ft. 6 ins. wide, with landings about half way down. Each landing is approached from the surface by two stairs parallel with the dock and entering from opposite directions; the steps of stairs are 12 ins. broad and 6½ ins. rise.

The caisson for closing the entrance is of iron, rectangular in shape, as was first used in 1850 to close the lock entrance at Keyham; with folding roadway and handrails, similar to the caisson with folding handrails and lowering and raising roadway deck adopted in 1867 by Sir Andrew Clarke, R. E., to close the entrance to the Royal Somerset Graving Dock, Malta; but instead of sliding, as at Malta, it is moved by rollers fixed under it, which run on broad iron rails laid on each side of the floor of the caisson chamber.

The caisson has a water-tight deck about half way between the bottom and top, and is ballasted with 180 tons of concrete ballast, 60 tons of

which is portable, being in 12-in. cubes which can be lifted out to enable the caisson to be floated out of its recess if required.

The whole of the cement used in the construction of the dock was the best quality of Portland. The proportions of gravel and broken stone and cement for the concrete were as follows: for the making of the triple cylinders, 5 to 1; floor and sides of dock and ballasting of caisson, 6 to 1, the concrete on the sides being supplemented by a plentiful supply of rubble; for the covering of the caisson chamber, 8 to 1; and for the filling of the concrete cylinders, 9 to 1.

The gravel for the concrete was mostly got from the excavations, the remainder was Thames gravel brought round from London as ballast, and a considerable quantity of the rubble stone was from the blasting of Elderslie Rock, already referred to.

All the concrete was mixed by Jamieson's patent mixers, and the stones were broken by Hope's patent stone breaker.

The granolithic altars consist of 3 parts of crushed granite to 1 of cement, and the granolithic-faced ashlar of 6 ins. of granolithic of the same quality, the remainder of the blocks being 5 to 1 concrete. The mortar for building the brickwork was composed of 1 part of cement to $2\frac{1}{2}$ of sharp sand; and for pointing, 1 part of cement to 1 of sand. All the sand was obtained from the excavations for the dock.

The dock is emptied by the pumping engines of No. 1 dock through a 5 ft.-9 in. bore cast-iron pipe; but this pipe having been put in simultaneously with the construction of No. 1 dock, for the second dock to be 2 ft. 10 ins. less in depth, the last few inches of water above the floor in No. 2 dock has to be emptied by an auxiliary pump, a 10-in. centrifugal, by Messrs. Easton & Anderson, London, driven by a 16-H. P. nominal gas engine, by Messrs. Crossley Brothers, Manchester.

The caisson was made by Messrs. Hanna, Donald & Wilson, Paisley; the caisson hydraulic engine, which can also be worked by hand, is by Messrs. Tannet, Walker & Co., Leeds; and a new hydraulic pumping engine, for working the accumulator for the hydraulic power required for the hauling engine of No. 2 dock and the capstans and sluice valves of both docks, was supplied by Messrs. Fullarton, Hodgart & Barclay, Paisley. The sluices were furnished by Messrs. Easton & Anderson.

All the three engines are underground, in roomy, white-glazed brick-lined houses, the two former being roofed over at the surface by

rolled beams and concrete, and furnished with Gourlay's prismatic lenses for lighting.

The author has no information as to when ferry-boats commenced to ply across the harbour, but they have now become an important means of public communication between the north and the south sides of the city and suburbs. The Clyde Trustees have, at present, 10 cross-harbour passenger ferry steamers, from 6 to 7½ H. P. nominal, licensed to carry from 93 to 110 passengers, nine of them having fire engines on board, for the service of the four cross-ferries within the limits of the harbour and for the two across the river below the harbour at Meadowside and Whiteinch respectively; and two vehicular and passenger ferries combined, one at Finnieston, about the center of the harbour, and the other at Govan, the western boundary of the same.

The ferry at Govan has been in existence for many years, by a boat worked by hand-wheels up to 1867, and since then by steam. The first steamer was of 15 H. P. nominal, having a single cart and carriage way in the center, accommodating three horses and carts and 50 passengers, or 200 passengers alone, and wrought on one chain stretched across the bottom of the river.

A second steamer for Govan Ferry, designed by the author, commenced working in 1875. It is 20 H. P. nominal, has two cart and carriage ways, one on each side, the passengers being accommodated in the center; carries eight horses and carts, and 140 passengers, or 500 passengers alone, and is wrought on two chains across the river, one on the inside of each cart and carriage way.

A vehicular ferry steamer of peculiar construction, designed and built by Messrs. William Simons & Co., Renfrew, was put on to ply across the harbour at Finnieston two and a half years ago, its main feature being an elevating deck which is raised and lowered by bevel and worm gearing, so that at any state of the tide the deck is brought to the same level as the quay.

The vessel has four screws to give her great manœuvering facilities, is 80 ft. long, 44 ft. broad, depth amidships, 12 ft., and draft amidships when loaded, 9½ feet. The hull is built of steel and the decking of iron. It is divided by 13 bulkheads, five of them transverse.

The elevating deck, which is 78 ft. long by 32 ft. broad, when in its lowest position rests on the iron deck. Nineteen feet of the width is for vehicles, and 6 ft. 6 ins. on each side is reserved for passengers.

Vertical screws of forged steel, six in number, three on each side, 7 ins. in diameter, carry the elevating deck; and are supported by six columns formed of two box girders, one on each side of each screw, 12 by 14 ins., channel section, placed 2 ft. apart, and on turning the screws by bevel gearing the elevating deck is moved. Each of the screws works in a manganese bronze casing, bolted between the two box girders forming each column, and placed so that the deck may rise 14 ft. The columns are held in position at top by longitudinal and transverse steel girders of I section, and to the sides of the vessel by similar girders; and on the top of the former, the wheelhouse, with steam steering gear is placed, with telegraphic communication to the engine-room.

The machinery for propelling the vessel and for operating the elevating deck is placed in one compartment in the center of the vessel under the iron deck, while at either side is a boiler. The boilers are horizontal tubular, 7 ft. in diameter by 7 ft. 6 ins. long, constructed of Siemens-Martin steel, for a working pressure of 150 lbs. to the square inch.

There are three horizontal triple-expansion engines, all of the same design and size. Cylinders, 9 ins., 14½ ins. and 24 ins. diameter, respectively, with a piston stroke of 18 ins. Two of the engines are placed athwartship, the one driving the line of shafting running fore and aft, and operating the port screws at both ends of vessel, while the other drives the shafting for the starboard screws. The third engine is placed between the two others, and lies with pistons working in a fore-and-aft plane, driving a line of shafting running athwartship and connected through spur and bevel wheels with two lines of fore-and-aft shafting of 4¼ ins. diameter wrought steel, geared on the respective sides to each of the vertical screws for moving the elevating deck.

The vessel accommodates 300 passengers and eight loaded carts with horses, or 700 passengers alone, and works across the river between a recess on the north side and two dolphins on the south side, and has proved a perfect success in every way.

The Trustees have also a rowboat ferry across the mouth of the Kelvin at Govan.

The Renfrew Burgh authorities maintain a steam vehicular ferry across the river at Renfrew, and Lord Blantyre one at Erskine.

The number of passengers conveyed across the river at the different ferries belonging to the Trustees for the year ended June 30th, 1892, was 9 054 429, and of vehicles 218 510, and the gross revenue derived therefrom amounted to £19 219 13s. 10d. The charge for crossing is one-half penny for each passenger, but 18 single-journey tickets are sold for sixpence.

In April, 1884, the Clyde Trustees established under the authority of Parliament a service of passenger steamers called *Cluthas*, from the word *Clutha*, the Gaelic name of the Clyde, to ply between Victoria Bridge, Glasgow and Whiteinch, a distance of 3¼ miles. These steamers, now ten in number, are twin-screw, from 74 to 102 ft. long by 13 to 17 ft. beam, licensed to carry from 235 to 360 passengers, ply at 10-minute intervals between these points, and call at various intermediate stations on both sides of the harbour, at the fare of one penny for the whole distance. During the year ended June 30th, 1892, they carried 2 949 661 passengers, the gross revenue from which was £12 373 11s. 9d.

The total number of persons in the exclusive service of the Trust, including about 400 engaged at the new dock and other new works, is 1 598.

Having now given a somewhat detailed account of the conversion of the river into a navigable water-way, and of the progress of the harbour up to date, the question may be fairly put, What about the cost? The gross total expenditure from the year 1770 till June 30th, 1892, amounted to the very moderate sum of £13 641 301 5s. 0d. Included in that amount is—

£471 194 15s. 7d. for the general management, officers' salaries, etc.
£425 997 5s. 7d. for the ground annuals, and feu duties.
£299 174 8s. 1d. for taxes, and
£4 287 073 7s. 11d. for interest on borrowed money.

For complete details as to the total expenditure, see Appendix I.

The gross revenue from July, 1752, to June 30th, 1892, amounted to £8 890 279 7s. 5d. For details see Appendix II.

The total debt due by the Trust as at June 30th, 1892, was £4 843 228 8s. 0d.

To show the nature of the expenditure and revenue for a year, a detailed abstract of each of these, from the annual accounts of the Trust for 1892, is given in Appendices III and IV.

While in 1656, Commissioner Tucker stated that there were only 12 vessels belonging to the merchants of the port, three of 150 tons each, one of 140, two of 100, one of 50, three of 30, one of 15, and one of 12, none of which came up to the town, the Board of Trade statistics for 1891 show Glasgow to be the third largest ship-owning port of the Kingdom, with 1 576 vessels of an aggregate tonnage of 1 316 809, as compared with Liverpool with 2 307 vessels of 1 994 903 tons, and London with 2 685 vessels of 1 500 572 tons.

Glasgow, in regard to entrances and clearances of vessels to and from foreign countries and British possessions, stands sixth in the list of British ports with 2 303 vessels of 2 657 057 tons, being surpassed by London, Liverpool, Cardiff, the Tyne ports, and Hull, while in regard to the coasting traffic it stands fifth with 16 271 vessels of 3 110 211 tons.

Glasgow is the birthplace of the Allan Line, the Anchor Line, the City Line and the Clan Line, of first-class steamers, by which constant communication is kept up with Canada, the United States, Africa, and India; while the famed Burns Line of mail steamers cross nightly to and from Belfast, in all sorts of weather, with such regularity that the town clocks of Greenock might be safely set by their arrival and departure. Aitken, Lilburn & Co.'s lines of sailing ships to Melbourne and Sydney leave nothing to be desired. Various other lines maintain frequent communication with other colonial and foreign ports, while the connections with the English, Irish and continental ports are numerous and regular. Nowhere can such a fleet of handsome and commodious river passenger steamers be seen as on the Clyde; the names of many of them have become household words for all that is luxurious and comfortable in pleasure sailing.

The first commerce of Glasgow was the curing and exporting of salmon caught in the river, and the curing and exporting of herrings brought by wherries from the West Highlands. The union of England and Scotland, consummated March 25th, 1707, though violently opposed and leading to riots of a serious character, yet gave to the commerce of Glasgow its first great impetus. The opening up to Scotland of trade with the colonies led its merchants to go into ship-owning on their own account instead of, as hitherto, chartering vessels from the port of Whitehaven and elsewhere in the Northwest of England, and ultimately gave them the largest share of the foreign export

trade and a monopoly of the tobacco trade of the Kingdom; so that, in the year 1772, out of 90 000 hogsheads of tobacco imported into Great Britain, Glasgow alone imported 49 000; and in the year preceding that of the American War of Independence, the imports into the Clyde were 57 143 hogsheads, the property of 42 merchants who realized princely fortunes.

The Declaration of Independence changed all this, and "fresh woods and pastures new" had to be sought for. Trade with the East and West Indies was opened up and cotton-spinning started. At this time the vast mineral deposits of the West of Scotland still lay many fathoms deep, waiting the genius of James Watt to supply the mighty power to bring them to the surface and to raise the strong blast to fuse them into use. The power-loom, introduced into Glasgow in 1773, and driven by a large Newfoundland dog, also waited his master-hand, which was at length so well applied that in 1846 the consumption of cotton in Scotland was 119 225 bales, the greater part being absorbed in Glasgow.

All this is now altered. Little tobacco is imported direct, and the consumption of cotton is much reduced; but in place of these, the imports of American and other produce in their infinite variety has largely increased. Glasgow has become a large distributing center for the Southwest of Scotland and the North of England, and trade in Spanish and other ores and in fruit has sprung up in recent years, which has more than made up for the loss of the tobacco, cotton and tea.

The mineral wealth of the district in coal, iron, lime, shale oil, etc., has also been largely developed; and the making and exporting of sugar machinery, locomotives and wrought-iron work has taken such deep root in Glasgow and neighbourhood that they will not easily be displaced. The Singer Sewing Machine Company, too, have, within the last few years, completed the erection of large sewing machine works on the north side of the Clyde, about 6 miles below Glasgow, which cover 46 acres of ground, and give employment to several thousands of men, women and children.

In no instance have river improvement works been attended with such beneficent results—commercial, industrial and social—as those of the Clyde, which has in recent years been indeed a gold-producing stream.

For the year ended June 30th, 1892, the chief exports from Glasgow Harbour were :

	Tons.
Ale, beer and porter	44 639
Bale and box goods	143 964
Bricks	53 530
Coal	1 267 699
Coal tar	17 651
Coke	8 159
Confections	6 617
Earthenware	10 579
Gas coal cinders	7 815
Grain	15 908
" manufactured	49 656
Iron and steel:	
Bar, bolt, rod and sheet	100 496
Blooms	1 485
Boilers	2 178
Bolts, nuts, rivets and spikes	5 782
Bridgework, girders and roofing	7 189
Castings	44 986
Fencing	1 826
Fish plates	383
Galvanized	3 027
Gas and water pipes, cast	66 411
Ore	11 341
Pig-iron	144 626
Puddled iron	2 385
Rails	1 071
Railway sleepers, wrought	3 701
Railway and tramway plant and material	2 780
Scrap	33 457
Tubing	14 381
Tires and axles	692
Machinery and machines	64 890
Manure, chemical	26 701
Oil—Scottish shale	20 214
Oils—all other kinds	8 641

	Tons.
Pitch	32 509
Spirits of all kinds	29 638
Timber	16 272
Animals:	
Horses, ponies, mules and asses	1 425
Cattle	1 219
Sheep	13 990
Lambs	6 767

For the same year the chief imports were:

Bale and box goods	48 695
Cake feeding of all kinds	12 577
Cement	63 869
Chalk	9 059
Chrome ore	16 091
Clay, china and stone	34 273
Coal	5 171
Cotton seed	7 515
Dyewood	6 420
Fish	19 321
Fruit	39 646
Grain	362 960
" manufactured	206 012
Hay	13 491
Ice	12 892
Iron and steel:	
Bar, bolt, rod and sheet	4 965
Blooms	529
Ferro-manganese	1 675
Girders	1 796
Ore	485 167
Pig-iron	65 776
Rails	2 600
Scrap	16 774
Linseed	7 549

	Tons.
Nickel ore	22 577
Nitrate of soda	9 866
Oils of all kinds	24 851
Potatoes	6 614
Provisions:	
Bacon and hams	14 155
Beef, mutton and pork	14 063
Bread	126
Butter	7 597
Cheese	9 077
Lard	3 884
Meats, fresh	3 545
" preserved	5 779
Pyrites	52 662
Rice and rice flour	4 636
Rosin	9 654
Salt	19 837
Sand	19 189
Soap	4 087
Spirits of all kinds	13 454
Stones	27 331
Sugar	21 579
Timber	137 819
Tobacco	3 136
Treacle	5 275
Turpentine	3 794
Wines of all kinds	4 682
Yarn	4 679
Animals:	
Horses, ponies, mules and asses	5 970
Cattle	163 425
Sheep	44 313
Lambs	43 350

The total exports were 2 594 213 tons, and the total imports 2 302 604 tons.

3. Rise and Progress of Ship-Building on the River and its Tributaries.

Of the numerous industries that flourish on the banks of the busy Clyde, the palm must be given to ship-building and marine engineering. These, as much as its commerce, have spread its fame over every portion of the habitable globe; its floating palaces traverse every sea. The Clyde took the lead in introducing the steamboat to the Old World, which in the short space of 80 years, has revolutionized the carrying trade of the world, and brought about that commercial intercourse between nations which has so vastly increased the comfort and happiness of the whole human race. The application of James Watts' inventions to steam navigation by Patrick Miller, William Symington and Henry Bell, and the improvement of the Clyde, most singularly coincided, and the further development of both still go hand in hand.

But for the continuous deepening of the river, while there might possibly have been a *Comet*, there could have been no *Iona*, no *Columba*, no *Lord of the Isles*, no *Livadia*, with its 153-ft. beam, no *Umbria*, no *Etruria*, no *City of New York*, no *City of Paris*, no *Campania*, no *Lucania*, launched from its banks above Dumbarton. So far, however, as depth of water was concerned, ship-building was always possible at Dumbarton, Port Glasgow and Greenock.

By 1839, four firms had established ship-building yards at Glasgow within the limits of the harbour: Tod & Macgregor and Thomas Wingate & Co. on the south side, the latter of whom engined the *Sirius*, built at Leith in 1837, the first British steamer to cross the Atlantic, and Robert Napier and Barclay Curle & Co., on the north side. Some few years thereafter two additional yards were established on the north side and four on the south side. All the yards but one on the north side and all but three on the south side have been forced out of the harbour by the ground they occupied being absorbed for quay extension.

The first removal was in 1846, to the west bank of the Kelvin at its junction near the Clyde, and the others followed as necessity required, one to the south side of the river, and the others to the north side of the river at Whiteinch, opposite, a distance of 1½ miles below the Kelvin; and another, Messrs. James & George Thomson's, to Clydebank, on the north side of the river below Renfrew, where the twin-screws

City of New York and *City of Paris* were built and engined. About 30 years ago, a new yard was established on the east bank of the Kelvin, at its junction with the Clyde.

Fully 20 years ago, Messrs. John Elder & Co. established on the south side of the river perhaps the most extensive private ship-building yard and marine engine works in existence, at Fairfield, Govan, now the property of the Fairfield Engineering and Ship-building Company, Limited, where the twin-screws *Campania* and *Lucania* were built and engined. About 15 years ago another yard was laid out on the north bank of the river at Clydebank.

There are upwards of forty ship-building yards in what may be termed the Clyde district. One yard is at Rutherglen three miles above Glasgow Bridge, where have been built many of the beautiful steam yachts and pleasure steamers which ply on our English lakes, on our Scottish lochs and on foreign waters; one at Blackhill on the Monkland Canal, one at Kirkintilloch and three at Maryhill on the Forth and Clyde Canal, five within the limits of the harbour; one at Patrick, immediately below the limits; two at Govan, three at Whiteinch, two at Renfrew, two at Clydebank, four at Paisley, one at Bowling, five at Dumbarton, seven at Port Glasgow, four at Greenock, and the remainder at Fairlie, Ardrossan, Troon and Ayr.

Lloyd's Ship-building Returns give the total number and tonnage of vessels launched in the United Kingdom, and built abroad, during 1892, to be—

659 steamers, with a gross tonnage of............	967 566
392 sailing ships, of a gross tonnage of..........	390 479
83 war ships, with a total displacement of.......	308 901 tons.

a total of 1 134 vessels and 1 666 946 tons, of which were built in the United Kingdom—

512 steamers, with a gross tonnage of............	841 356
169 sailing ships, with a gross tonnage of........	268 594
30 war ships, with a total displacement of......	151 157 tons.

or a total of 711 vessels and 1 261 107 tons, the Clyde taking the lead with an output of—

133 steamers, with a gross tonnage of............	140 350
81 sailing ships, with a gross tonnage of........	159 002
3 war ships, with a total displacement of......	22 826 tons.

or a total of 217 vessels and 322 178 tons.

The Tyne district is next with a total of 101 vessels of 219 936 tons, followed by the Wear with a total of 75 vessels of 186 440 tons, and Middlesboro', and Stockton-on-Tees with 46 vessels of 103 725 tons.

The first iron vessel built in Scotland was the *Vulcan*, by Thomas Wilson, at Faskine on the Monkland Canal, about 11 miles from Glasgow. It was launched on May 28th, 1818, and until within the last 20 years was engaged in carrying coal from the Forth and Clyde Canal to ports on the Clyde. To England, however, belongs the honor of launching, in 1821, the first iron steamer, the *Aaron Manby*, built at Horsley.

The first iron steamer built on the Clyde was the *Aglaia*, in 1827, for passenger traffic on Loch Eck; and the first to ply on the Clyde was the *Fairy Queen*, built at the Old Basin Foundry, Glasgow, about a mile and a half from the river, to which it was brought bodily and launched in 1831.

4. Short Description of Other Harbours on the River.

A description of these harbours, to do them justice, would require a separate paper, written by one with more local and special knowledge of them than the author possesses.

Renfrew.—About 5 miles below Glasgow Bridge is Renfrew. A royal burgh, its proximity to its great neighbour has over-shadowed it; from time to time its authorities have made laudable efforts to give it a harbour, but have, as yet, had to be content with an extension of the quayage on the town side of a burn called the Pudzeoch.

Paisley.—Next in order is Paisley, situate on the River Cart, about 3¼ miles from the junction of that river with the Clyde, now a thriving thread-spinning, corn-flour-producing, shawl-manufacturing, ship-building and general engineering town. It allowed Glasgow to take the lead in river improvement and in former years got more than one Act of Parliament to deepen, straighten and widen its river without much good result. Under an act passed in 1885, the quayage at Paisley has been largely extended, and the river is being deepened to 18 ft. below high water of spring tides. Financial difficulties, however, have for the present stopped the completion of the work.

Bowling Harbour.—This harbour comes third, and is about 11 miles below Glasgow. It has a tidal basin of 12 acres, the joint property of the Clyde Trustees and the Caledonian Railway Company, used by the

latter in connection with the Forth and Clyde Canal of which they are owners, and by the former in the laying-up for the winter of the extensive fleet of passenger steamers plying in summer on the waters of the Clyde and adjoining lochs. Here, side by side, may be seen, dismantled and silent, the famous *Iona*, *Columba*, *Lord of the Isles*, and many other river steamers, which, during the summer months, are crowded with tourists from all parts of the world, who view with admiration the enchanting scenery of the Western Highlands.

Dumbarton.—The present authorities, inspired with much broader views on the harbour question than were their predecessors of 1658, in 1881 carried through Parliament a bill for the improvement of the River Leven, and the providing of increased quay accommodation; but beyond some deepening, not much has yet been done.

Port Glasgow.—The old harbours were acquired by the municipal authorities of this port in 1864, from the magistrates of Glasgow, on payment to the latter of 5s. per pound sterling on the amount of the debt on them. A considerable amount of iron ore is discharged there and sent to the various iron works in the west of Scotland.

The harbour accounts for the year ended June 30th, 1892, show a gross revenue of £4 813 3s. 6d., and a total expenditure of £4 599, of which £2 652 15s. were paid for interest on borrowed money. The total debt of the Trust is £71 262 11s. 3d.

Greenock.—Glasgow's greatest rival and ancient superior, and the birthplace of James Watt, a few years ago, through the enterprise of its leading men, engaged in harbour extension of an important character, chiefly in the construction of the James Watt Dock. This unfortunately led to a serious crippling of its harbour finances, in consequence of the shipping trade of Glasgow refraining from making use of the accommodation it afforded. The aid of Parliament had to be obtained to rearrange the harbour debt, and it is gratifying to be able to say that, by this rearrangement, and the gradual development of trade in the district, the financial position of the harbour is rapidly improving. The gross revenue for the year ended September 5th, 1892, was £64 667 16s. 6d., and the total debt £1 529 211 14s. 7d. The harbour has a total water area of 52 acres, and there are three public and two private graving docks.

The Board of Trade returns for 1891 show that 309 vessels, of 240 100 tons, belong to Greenock; that the entrances and clearances of

vessels to and from foreign countries and from British possessions were 529 vessels and 438 529 tons, and the coasting traffic 15 760 vessels of 2 950 434 tons.

Sugar importing and refining, timber importing, and ship-building and marine engineering, form the staple industries of the town; and the ship-builders and marine engineers higher up the river, find in the ship-builders and engineers of the town keen and often successful competitors in the obtaining of contracts.

The principal imports for the year ended September 5th, 1892, were—

Coal	11 585	tons.
Iron, ore	33 935	"
" pig	8 540	"
Lime	2 460	"
Sand	6 859	"
Sugar	149 667	"
Timber, pine and teak	101 568	loads.
" oak, elm, birch, etc.	17 608	"
" deals	12 037	"

And the principal exports were—

Coal	143 825	tons.
Iron, wrought	4 686	"
" pig	4 530	"
Manure	3 793	"
Sugar	84 795	"

The natural Clyde begins at Greenock, where the artificial Clyde terminates, and the panorama thence to the Atlantic is one of exquisite beauty, and must be seen to be fully appreciated; the serrated peaks of the Argyleshire Hills, rising in their sublimity towards heaven, on the north, the Island of Bute and the two Cumbraes guarding the entrance from the sea, while, still farther seaward, Goatfell in Arran rears its lofty head proudly to the sky, and away in the far distance, stands forth, lonely in its utter isolation, the "craggy ocean pyramid," Ailsa Craig.

The numerous watering places, with their infinite variety of architectural designs, close-shaven lawns and expanses of foliage, which fringe both sides of the estuary, in some places for miles contin-

ously; the innumerable white-winged yachts skimming its surface in all directions, the outward or inward bound Atlantic liner ploughing its way through the azure waters, the full-sailed Indiaman gliding slowly along, and ever and anon the swift passenger steamer, dashing from pier to pier, make during the summer months a scene which, once gazed upon, can never be forgot.

APPENDIX I.

CLYDE NAVIGATION.

ABSTRACT OF TOTAL EXPENDITURE FROM THE YEAR 1770 TO JUNE 30TH, 1892.

	£.	s.	d.
General management, officers' salaries, etc.....	471 194	15	7
General expenditure, repairs and upkeep of works, damage to fishings, etc............	807 088	18	1
Extraordinary repairs, Parliamentary opposition, etc..............................	53 593	3	0
Crane wages and repairs	137 946	17	9
Ferries, wages, and repairs of boats...........	298 018	17	1
Ground annuals and feu duties...............	425 997	5	7
Law and Parliamentary expenses.............	96 676	13	8
Police..	76 982	17	7
Rhones and planks for shipping..............	35 984	15	8
Water supply for vessels.....................	47 167	9	6
Taxes	299 174	8	1
Lighthouses on river.........................	16 369	16	9
Interest on borrowed money..................	4 287 073	7	11
Dredging in river and harbour. Repairs of machines, punts, etc., including new machines, tugboats, barges, punts and machinery....	1 731 571	14	0
Land purchased for enlargement of harbour...	1 229 353	16	4
Land purchased for widening river...........	178 289	11	6
New hall and offices for Trustees.............	42 850	15	11
Acts of Parliament...........................	72 568	5	11
Construction of works, harbour...............	1 223 245	4	3
" " river	438 408	13	8
Elderslie rock	70 414	0	5
Engineering and surveying	20 032	14	11
Ballast..	1 203	0	2
Kingston Dock, exclusive of land............	84 544	5	4
Dumbarton exemptions.......................	5 097	5	2

	£.	s.	d.
Dalmuir workshops	28 718	4	6
Harbour workshops..........................	1 817	9	3
Steam ferry-boats, etc..........................	37 878	17	9
Harbour passenger steamers, landing stages, etc.	33 771	2	0
Swinging buoys in Gareloch..................	1 154	14	10
Measured mile—Gareloch....................	34	19	1
Harbour tramways	42 212	14	3
Swing bridge at Kingston Dock..............	12 793	19	2
No. 1 graving dock, exclusive of land..........	134 867	9	11
No. 2 " " "	108 283	4	3
No. 3 " " constructing	20 765	0	0
Queen's Dock, exclusive of land..............	825 212	8	11
Workmen's houses at Dalmuir................	15 328	18	0
Gas-lighted buoys and lightship................	5 289	1	8
Cessnock Dock, constructing..................	196 669	19	10
" Acts of Parliament..............	11 774	2	9
Quay wall, entrance, Cessnock Dock...........	13 880	5	1
	£13 641 301	5	0

APPENDIX II.

CLYDE NAVIGATION.

STATEMENT OF GROSS REVENUE FROM JULY, 1752, TO JUNE 30TH, 1892.

	£	s.	d.		£.	s.	d.
From July, 1752, to July, 1770..	£147	0	10	1787............	1 975	16	4
				1788............	2 064	5	9
One year to July, 1771..........	1 044	10	0	1789............	2 153	15	6
				1790............	2 239	0	4
1772............	1 220	1	9	1791............	3 175	14	1
1773............	1 494	1	0	1792............	2 739	5	7
1774............	1 454	4	4	1793............	2 840	17	11
1775............	402	3	8	1794............	2 936	14	11
1776............	1 984	0	7	1795............	2 836	5	9
1777	1 397	0	7	1796............	3 649	14	4
1778	1 733	19	5	1797............	3 182	6	0
1779............	1 540	1	8	1798............	3 199	1	6
1780............	1 515	8	4	1799............	3 233	18	3
1781............	1 721	5	8	1800............	3 319	16	1
1782............	1 420	16	8	1801............	3 400	10	9
1783............	1 450	16	8	1802............	4 085	15	11
1784............	1 120	0	0	1803............	4 640	16	10
1785............	3 256	18	10	1804............	4 193	7	7
1786............	1 980	14	10	1805............	4 065	10	5

	£.	s.	d.
1806	4 299	14	3
1807	5 000	5	9
1808	5 472	0	9
1809	5 407	9	8
1810	6 676	7	6
1811	4 755	3	8
1812	4 597	19	7
1813	5 169	13	9
1814	5 275	6	11
1815	5 902	2	8
1816	5 843	7	8
1817	7 028	0	7
1818	7 732	18	11
1819	7 386	2	10
1820	6 328	18	10
1821	8 070	2	2
1822	7 984	3	8
1823	8 380	16	4
1824	8 555	0	0
1825	8 367	11	7
1826	16 204	6	6
1827	14 316	15	9
1828	17 669	14	10
1829	20 194	10	4
1830	20 296	18	6
1831	18 932	0	7
1832	22 496	0	3
1833	21 578	5	2
1834	22 859	14	10
1835	33 676	16	3
1836	37 544	5	5
1837	37 644	16	0
1838	39 030	1	0
1839	47 879	11	10
1840	46 536	14	0
1841	49 665	15	7
1842	40 678	16	8
1843	43 301	2	0
1844	41 286	18	8
1845	45 869	10	11
1846	51 198	12	2
1847	59 017	2	9
1848	60 621	8	1
1849	59 034	14	1
1850	64 243	14	11
1851	68 875	4	9
1852	76 077	9	4
1853	77 919	18	6
1854	86 580	5	11
1855	73 943	9	1
1856	74 995	7	9
1857	82 797	10	7
1858	78 783	17	6
1859	90 816	17	7
1860	97 983	18	1
1861	105 768	11	0
1862	111 493	10	2
1863	118 083	7	10
1864	121 380	13	9
1865	121 587	11	11
1866	125 787	10	0
1867	131 892	2	6
1868	143 840	17	3
1869	150 136	4	5
1870	164 093	2	10
1871	164 188	18	7
1872	174 200	12	2
1873	182 906	15	2
1874	192 127	16	11
1875	196 326	18	10
1876	198 526	19	6
1877	208 732	1	0
1878	217 100	0	3
1879	211 501	11	8
1880	223 709	0	8
1881	248 061	14	0
1882	264 549	8	3
1883	283 998	8	5
1884	291 182	4	11
1885	291 658	4	11
1886	282 912	1	3
1887	287 933	17	9
1888	311 495	1	6
1889	331 492	18	9
1890	356 202	11	3
1891	354 580	11	8
1892	369 226	6	5
	£8 890 279	7	5

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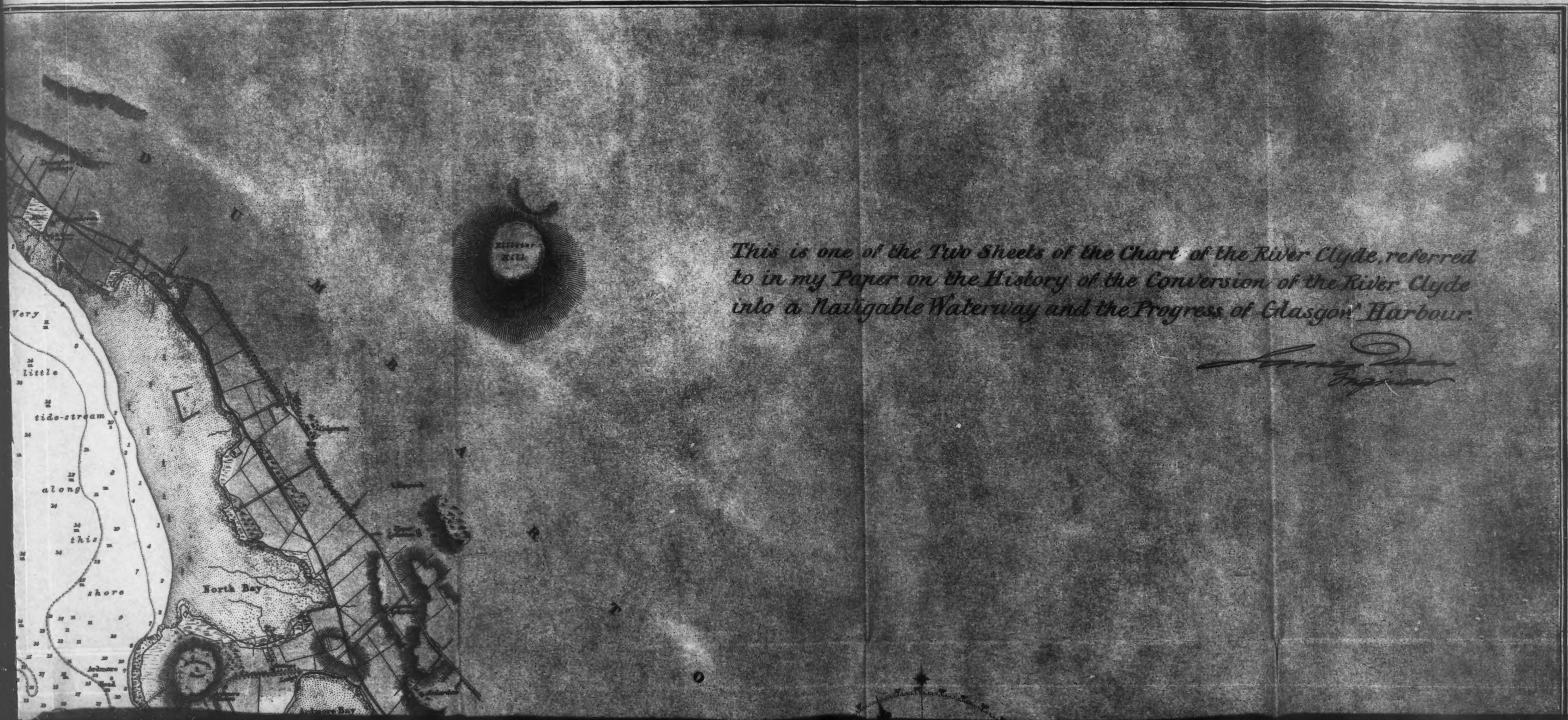
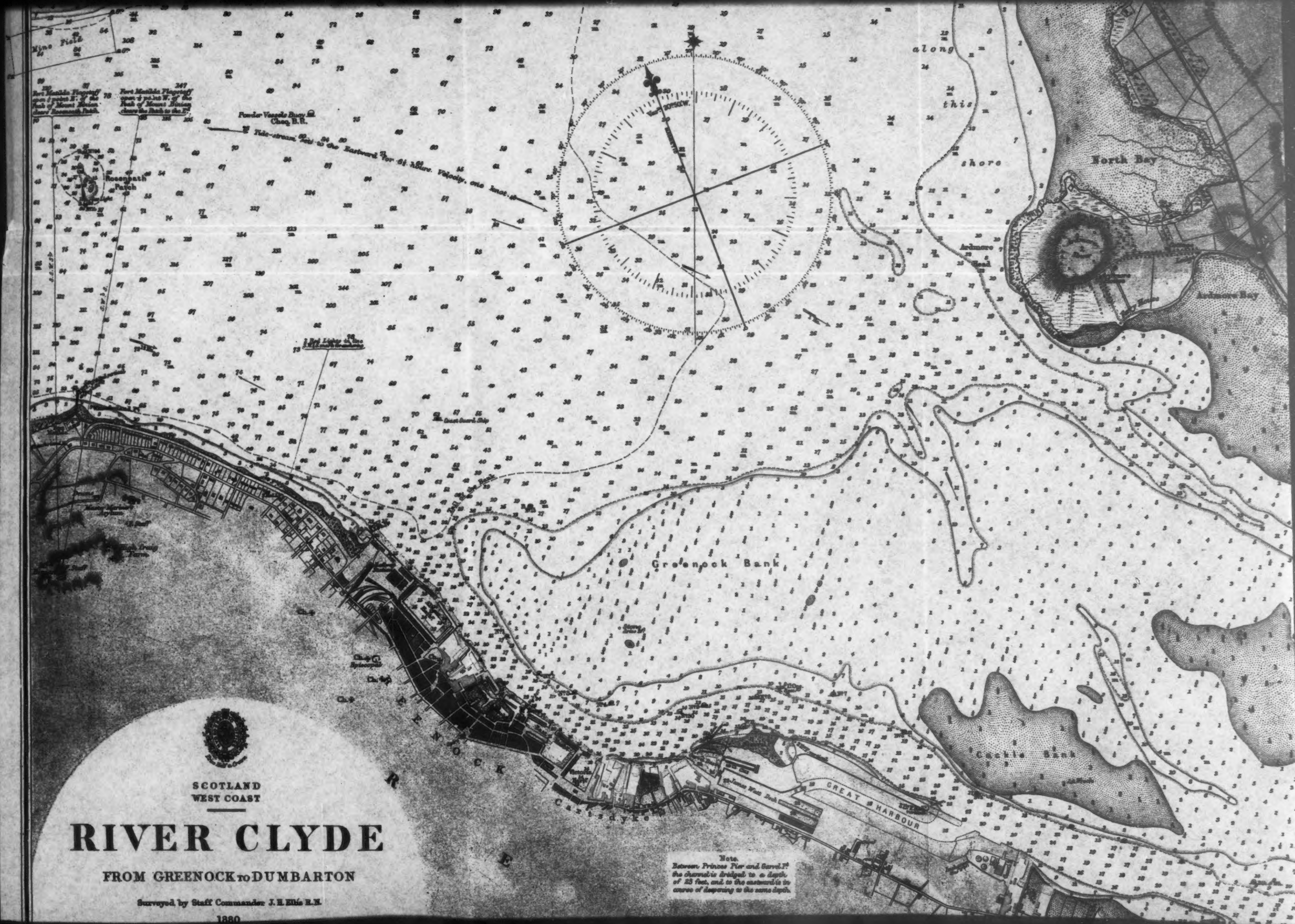
HELENSBURGH
Good anchorage
Roseneath Bay
Mickle Rose Bay
Roseneath Pt.
Very little tide-stream along this shore
North Bay
Mine Field
Fort Matilda Flagstaff open ½ point E. of the Peak of Mount Binian clears Roseneath Patch
Fort Matilda Flagstaff open ½ point W. of the Peak of Mount Binian clears the Patch to the E.
Roseneath Patch
Powder Vessels Buoy
Cheq. B.R.
Tide-stream sets to the Eastward for 6½ hours. Velocity, one knot.
Ardmore

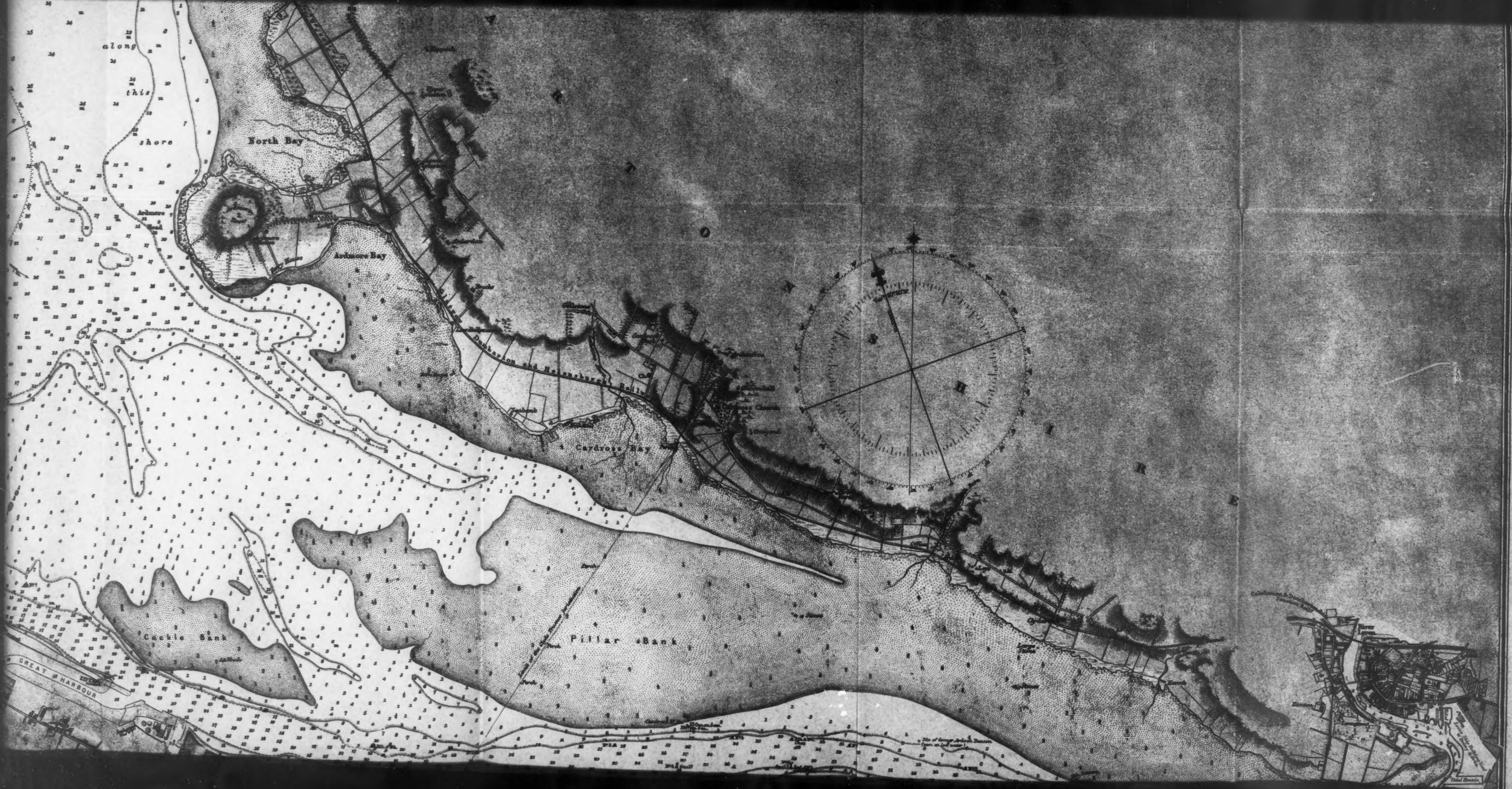
VOL. XXIX No. 606.

TRANS. AM. SOC. CIV. ENG'RS.
DEAS ON RIVER CLYDE
AND GLASGOW HARBOUR.
PLATE I.

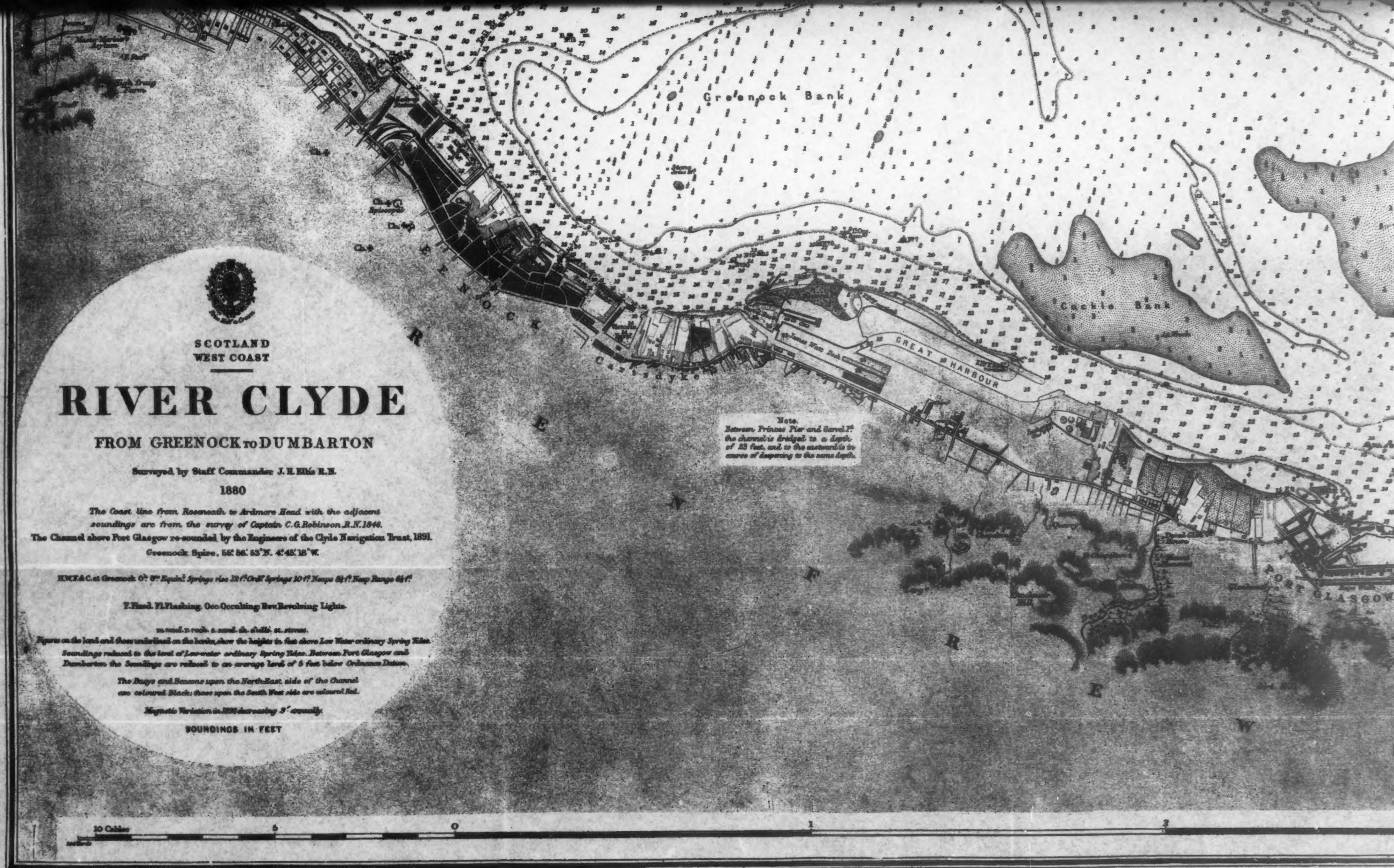




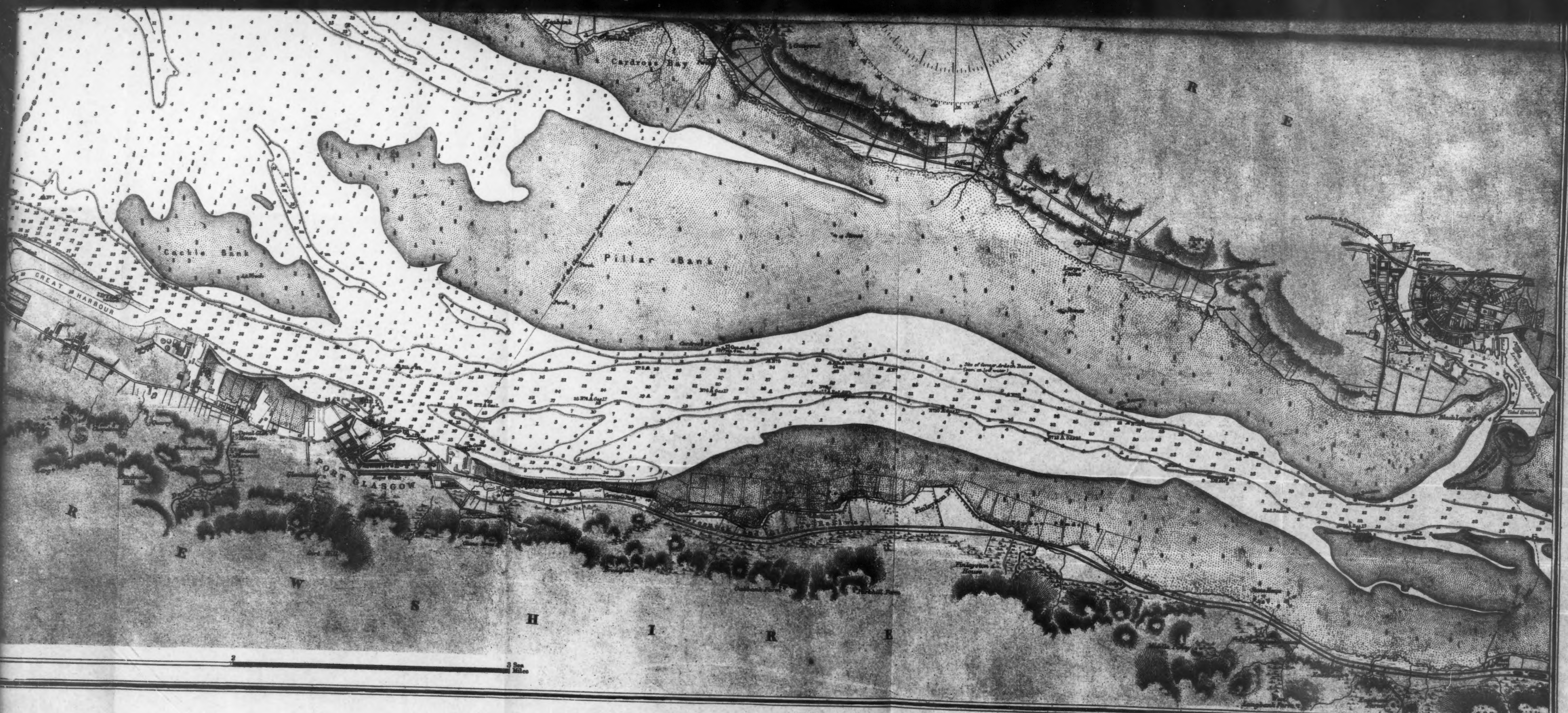
SCOTLAND
WEST COAST
RIVER CLYDE
FROM GREENOCK TO DUMBARTON
Surveyed by Staff Commander J. H. Ellis R.N.
1880
Note.
Between Princes Pier and Garvel Pt the channel is dredged to a depth of 23 feet, and to the eastward is in course of deepening to the same depth.
Greenock Bank
Cockle Bank
North Bay
Ardmore
Ardmore Bay
GREAT HARBOUR
Cartsdyke
G R E E N O C K
Rosneath Patch
along this shore



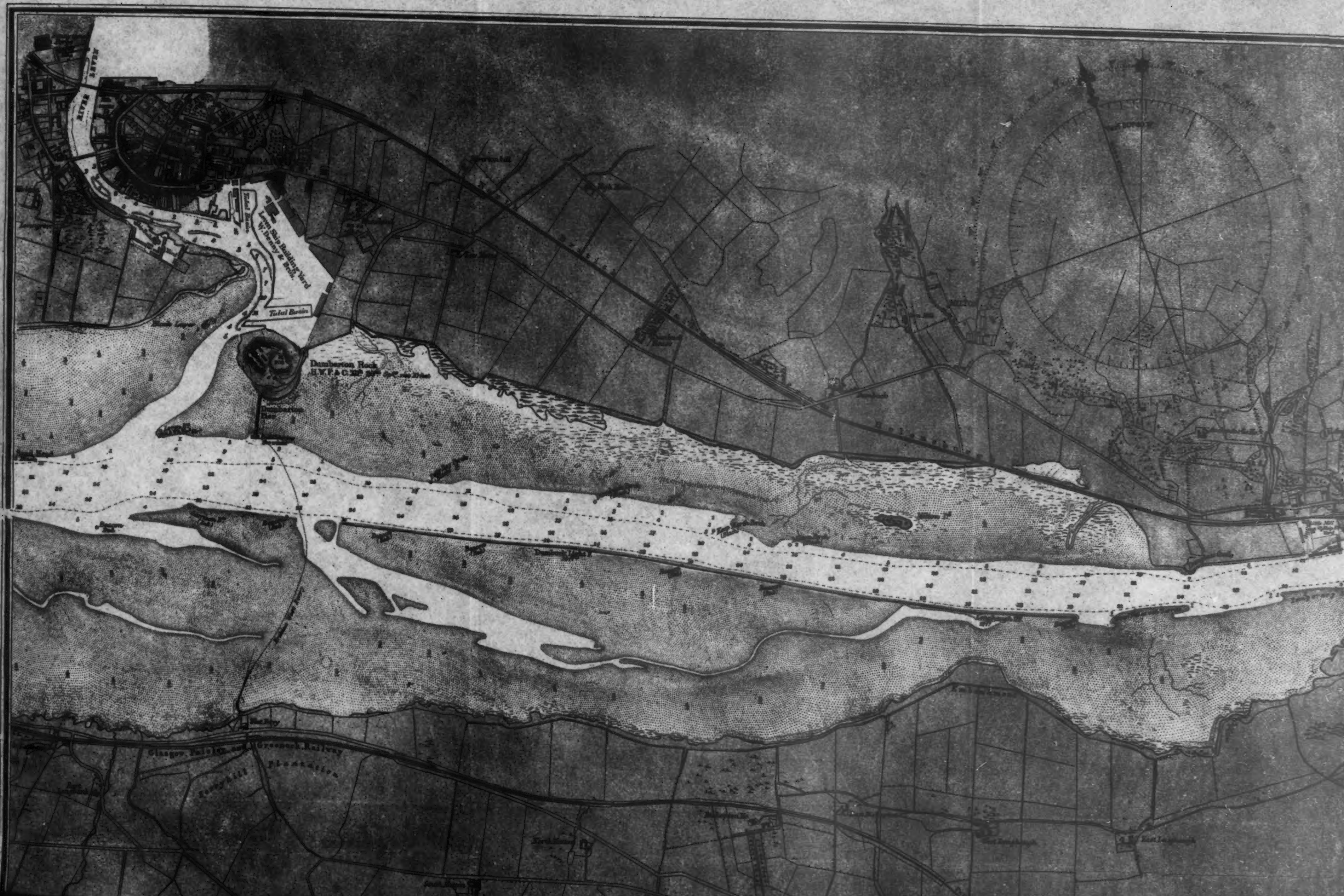
along
this
shore
North Bay
Ardmore Bay
Cardross Bay
Cockle Bank
Pillar Bank
GREAT HARBOUR



SCOTLAND
WEST COAST
RIVER CLYDE
FROM GREENOCK TO DUMBARTON
Surveyed by Staff Commander J. H. Ellis R.N.
1880
The Coast line from Roseneath to Ardmore Head with the adjacent soundings are from the survey of Captain C. G. Robinson R.N. 1846.
The Channel above Port Glasgow re-sounded by the Engineers of the Clyde Navigation Trust, 1891.
Greenock Spire, 55° 56′ 53″ N. 4° 45′ 18″ W.
F. Fixed. Fl. Flashing. Occ. Occulting. Rev. Revolving Lights.
Figures on the land and those underlined on the banks, show the heights in feet above Low Water ordinary Spring Tides.
Soundings reduced to the level of Low-water ordinary Spring Tides. Between Port Glasgow and Dumbarton the Soundings are reduced to an average level of 5 feet below Ordnance Datum.
The Buoys and Beacons upon the North East side of the Channel are coloured Black; those upon the South West side are coloured Red.
SOUNDINGS IN FEET
Greenock Bank
Cockle Bank
GREAT HARBOUR
Cartsdyke
GREENOCK
RENFREW
PORT GLASGOW
Note.
Between Princes Pier and Garvel Pt. the channel is dredged to a depth of 23 feet, and to the eastward is in course of deepening to the same depth.
10 Cables
5
0
1
2

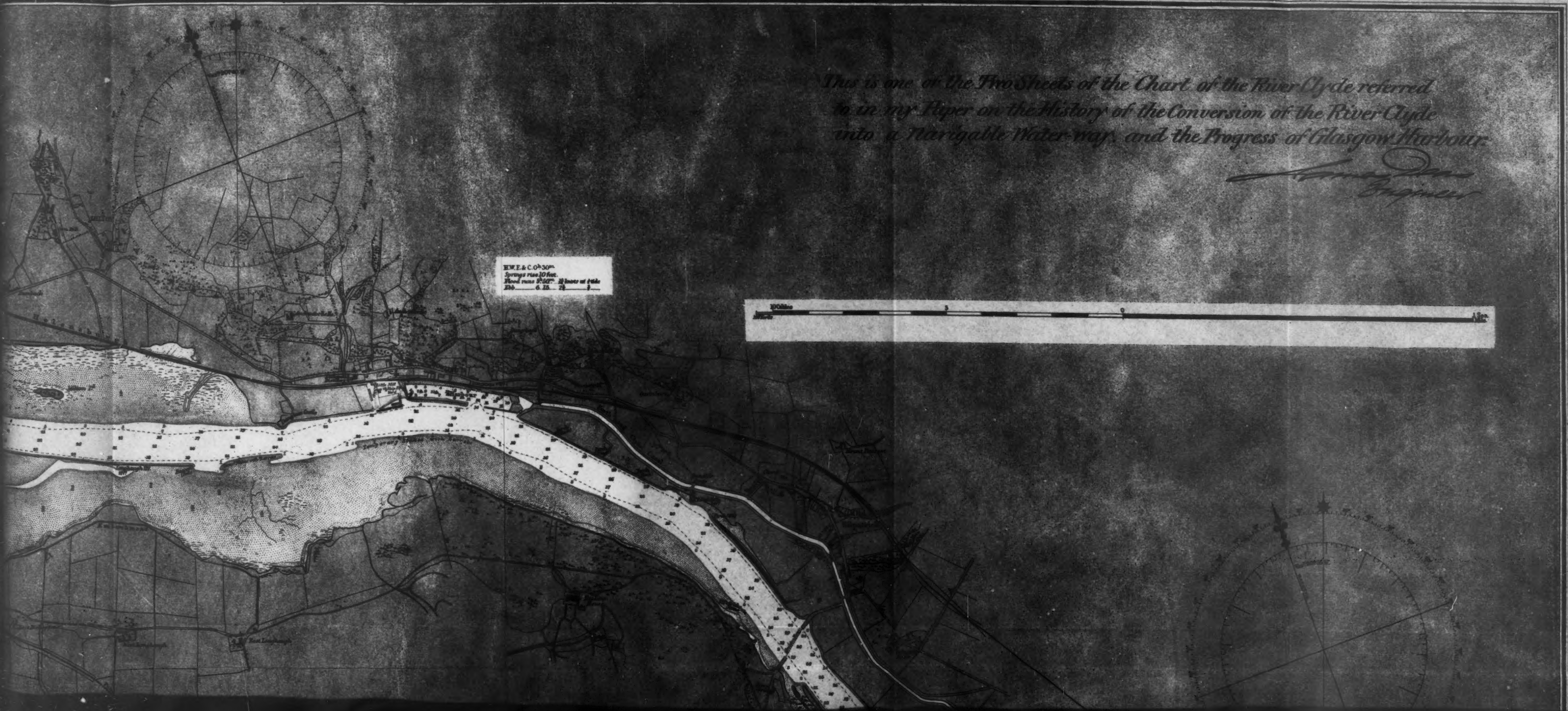


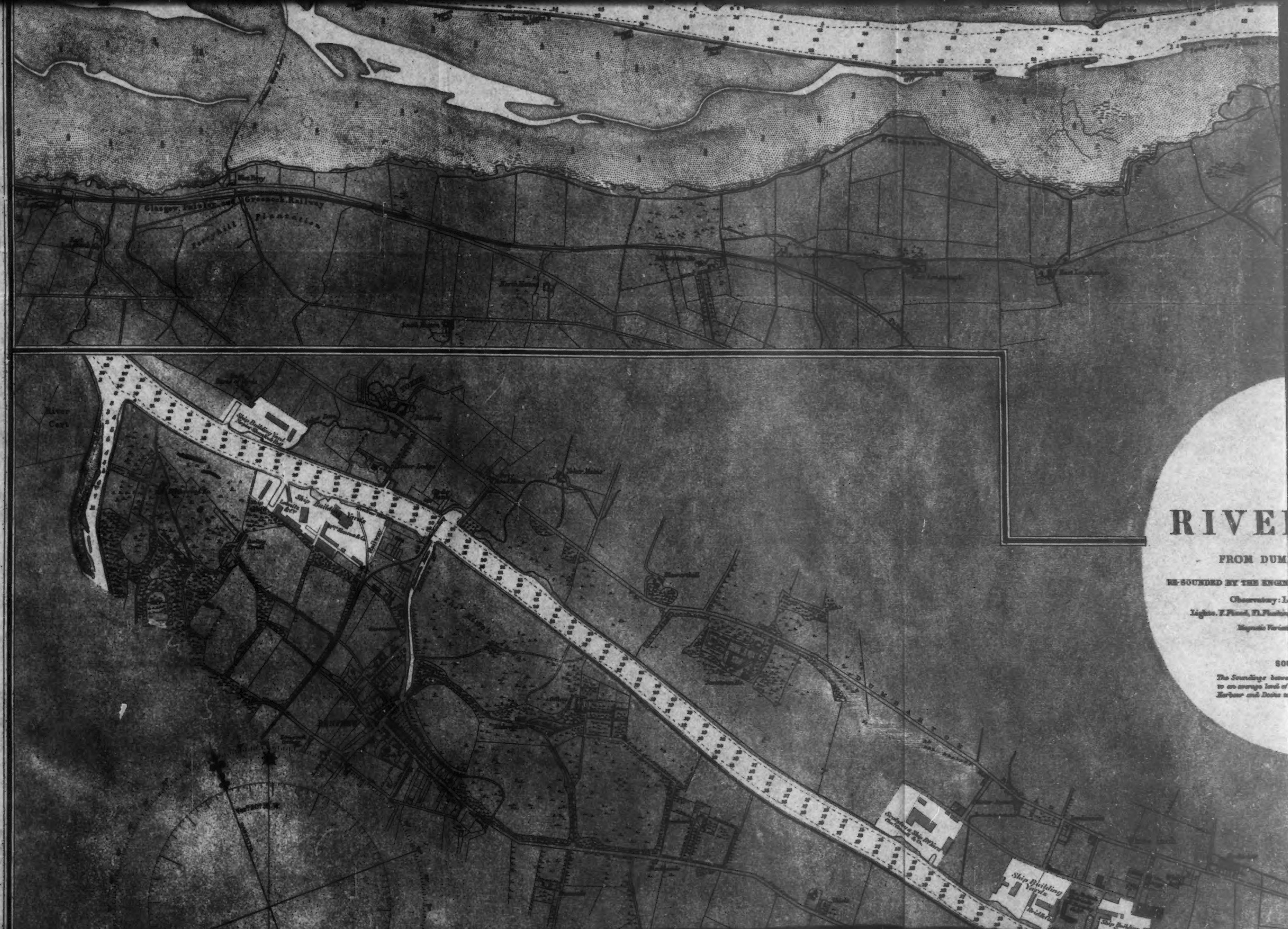
Cardross Bay
Pillar Bank
Cockle Bank
GREAT HARBOUR
PORT GLASGOW
R E W S H I R E



RIVER LEVEN
Tidal Basin
Leven Ship Building Yard W. Denny & Bros.
Tidal Basin
Dumbarton Rock
Dumbarton Pier
Glasgow, Paisley and Greenock Railway
Plantation

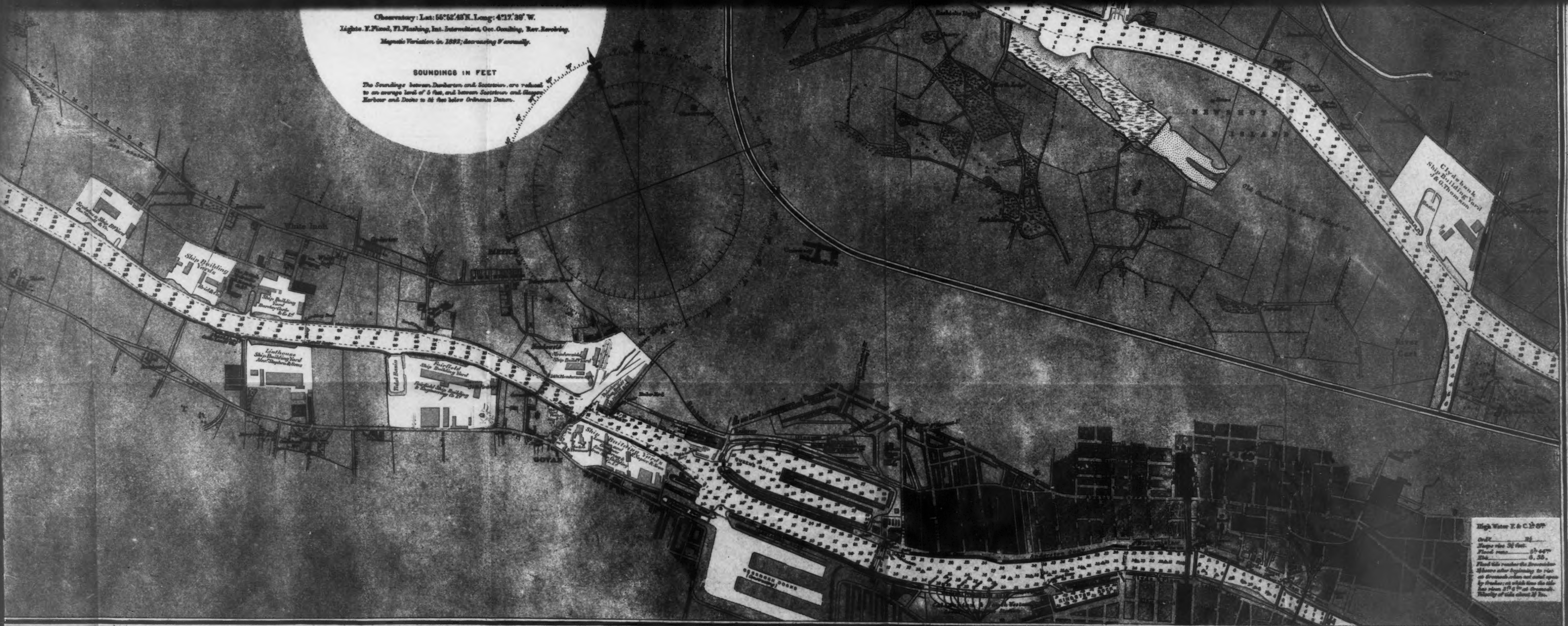
TRANS. AM. SOC. CIV. ENG'RS.
DEAS ON RIVER CLYDE
AND GLASGOW HARBOUR.
PLATE II.



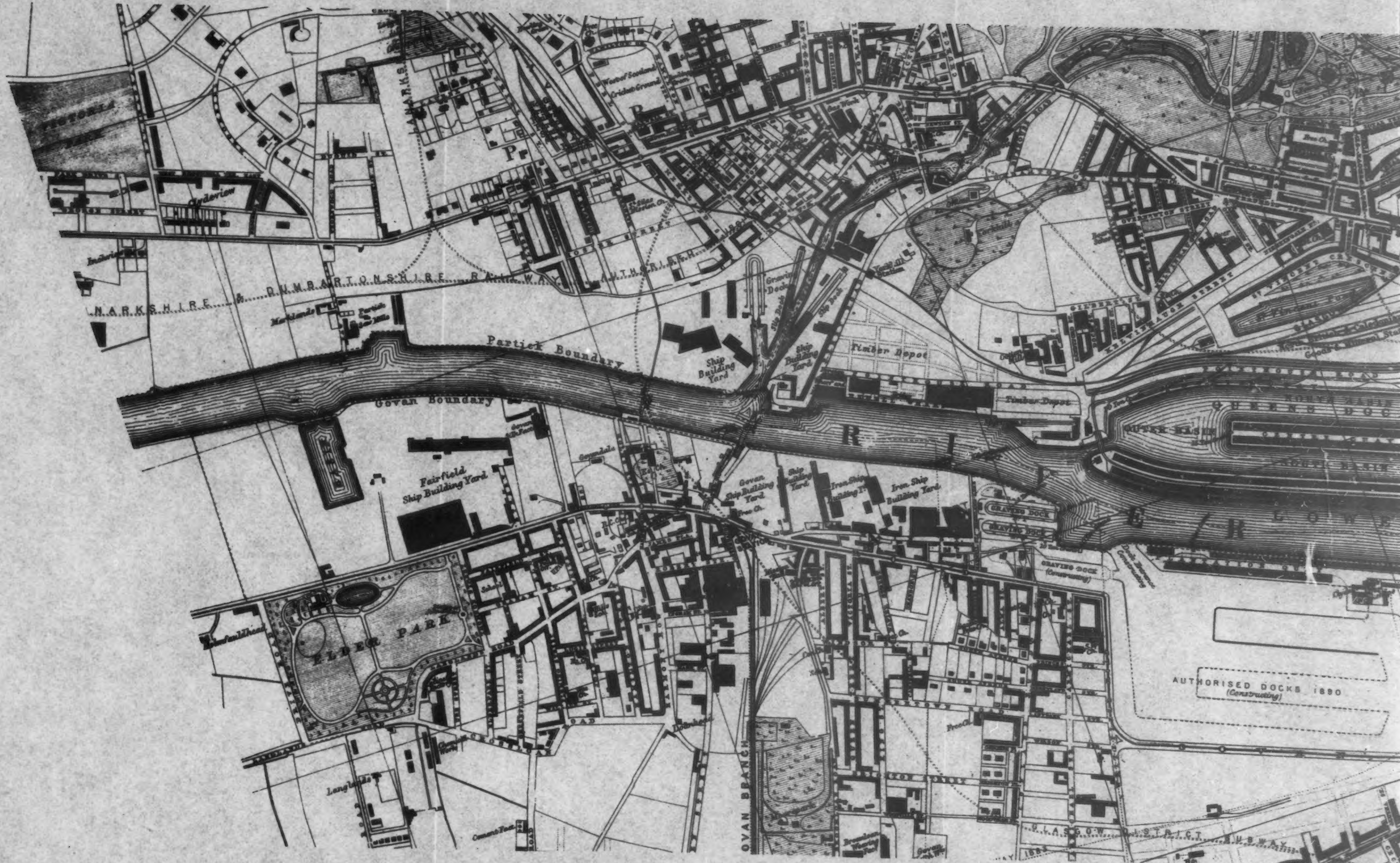

RIVE
FROM DUM
RE-SOUNDED BY THE ENGIN
Observatory: L
Lights. F.Fixed, Fl.Flashin
Magnetic Varia
SOU
The Soundings betwe
to an average level of
Harbour and Docks t
Glasgow, Paisley and Greenock Railway
Plantation
Ship Building Yard
Ship Building Yards
River Cart
DUMBARTON


SCOTLAND
WEST COAST
RIVER CLYDE
FROM DUMBARTON TO GLASGOW
RE-SOUNDED BY THE ENGINEERS OF THE CLYDE NAVIGATION TRUST, 1891.
Observatory: Lat: 55°52'43"N. Long: 4°17'39" W.
Lights. F. Fixed, Fl. Flashing, Int. Intermittent, Occ. Occulting, Rev. Revolving.
SOUNDINGS IN FEET
NEWSHOT ISLAND
Clydebank Ship Building Yard

FROM DU
RE-SOUNDED BY THE EN
Lights. F. Fixed, Fl. Fla
The Soundings
to an average lev
Harbour and Dock
Ship Building Yards
Reid & Co.
Ship Building Yard
Linthouse Ship Building Yard Alex[r] Stephen & Sons
Tidal Basin



Observatory: Lat: 55°52'43"N. Long: 4°17'39" W.
Lights. F. Fixed, Fl. Flashing, Int. Intermittent, Occ. Occulting, Rev. Revolving.
Magnetic Variation in 1892; decreasing 8' annually.
SOUNDINGS IN FEET
The Soundings between Dumbarton and Scotstoun, are reduced to an average level of 5 feet, and between Scotstoun and Glasgow Harbour and Docks to 8½ feet below Ordnance Datum.
Clydebank Ship Building Yard J & G Thomson
Ship Building Yards
Linthouse Ship Building Yard
Fairfield Ship Building Yard
GOVAN


Clydeview
LANARKSHIRE & DUMBARTONSHIRE RAILWAY
Partick Boundary
Govan Boundary
Fairfield Ship Building Yard
ELDER PARK
Timber Depot
Ship Building Yard
QUEENS DOCK
GRAVING DOCK (Constructing)
AUTHORISED DOCKS 1890 (Constructing)
GOVAN BRANCH
GLASGOW DISTRICT SUBWAY

DEAS ON RIVER CLYDE AND GLASGOW HARBOUR.
PLATE III.

APPENDIX III.

CLYDE NAVIGATION.

DETAILED ABSTRACT OF EXPENDITURE FOR THE YEAR ENDED JUNE 30TH, 1892.

	£	s.	d.
General management and office expenses	12 037	0	2
Harbour expenses	22 032	18	9
General expenses	8 508	14	1
Law and Parliamentary expenses	1 178	13	8
Sheds	595	3	8
Taxes	19 500	12	8
Lighthouses on river	196	1	7
Dikes and beacons	1 433	13	7
Graving docks	2 470	14	9
Cranes	5 405	2	5
" coaling and mineral	7 832	3	4
Ferries, Harbour	10 451	17	10
" Govan	5 703	19	11
Harbour passenger steamers	10 946	15	4
Planks and rhones	1 761	11	3
Water	1 919	15	2
Weighing machines	354	13	0
Properties	490	9	1
Dredging account, proportion for maintenance	26 632	2	11
Ground annuals and feu duties	13 070	9	9
Interest and annuities	176 449	9	8
	£328 972	2	7

	£	s.	d.
Surplus revenue	40 254	3	10

APPENDIX IV.

CLYDE NAVIGATION.

DETAILED ABSTRACT OF REVENUE FOR THE YEAR ENDED JUNE 30TH, 1892.

	£	s.	d.
Tonnage dues on vessels	79 473	2	0
Dues on goods	201 022	11	9
Rents for timber yards and offices	2 924	1	9
Quay rents	215	8	0

	£.	s.	d.
Harbour tramways	1 539	15	2
Lower stages of river	1 952	12	2
Miscellaneous	1 838	4	6
Graving docks	11 458	6	2
Crane dues	9 265	5	2
Coaling and mineral cranes	10 663	4	4
Ferries, Harbour	13 132	12	0
" Govan	6 087	1	10
Harbour passenger steamers	12 373	11	9
Planks and rhones	1 096	13	1
Water	5 495	10	1
Weighing	1 614	16	4
Rents	7 536	13	9
Funded debt premiums	1 536	16	7
	£369 226	6	5

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

607.

(Vol. XXIX—July, 1893.)

DESCRIPTION OF THE LOWER WESER AND ITS IMPROVEMENT.

By L. FRANZIUS, Ober-Bau-Director, at Bremen, Germany.

Translated from the German by T. H. McCANN, M. Am. Soc. C. E., assisted by ALBERT BEYER, Chairman of the Architectural Branch of the German Technical Society of New York.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

I. GENERAL HYDROGRAPHICAL DESCRIPTION OF THE RIVER WESER, IN PARTICULAR PRIOR TO THE COMMENCEMENT OF THE IMPROVEMENT.

The River Werra flowing from the Thüringer forests, and the River Fulda flowing from the Vogelsgebirge and the Rhön, unite at Münden, forming there the River Weser. From Münden to Bremen, a distance of 366 km., the river is called the Upper Weser, and for a distance of 69 km., extending from Bremen to Bremerhaven, the Lower Weser. The

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

effluent of the river to the open sea proper, for a distance of about 59 km., is called the Outer Weser. The first stretch has about 41 600 sq. km., and the last two have, besides, about 6 600 sq. km. of drainage area. About 27 500 sq. km. of the first area embraces mountainous and steep hilly land, so that during freshets the rise in the river is very rapid and considerable. The average descent of the upper 45 km. is as follows: from Münden to Karlshafen, 1 : 2 100; at rapids, however, it is 1 : 300. In the second stretch of 160 km., from Karlshafen to Minden, interrupted by slack water, caused by a dam at Hameln, it is 1 : 3 000; in the last 161 km., from Minden to Bremen, it decreases from 1 : 4 000 to 1 : 6 500.

The mean annual water-mark at Münden lies 114.6 m., and that at Minden, 35.3 m., above the corresponding water datum at Bremen, which was established from observations taken during the years 1870 to 1879, and was found to read on the principal gauge at Bremen 0.714 m., as shown in Table No. 2. The volume, the corresponding water levels and the velocities of the upper river are given in Table No. 3.

TABLE No. 2.

COMPARISONS OF UPPER-WATER READINGS ON THE GAUGE AT THE GRAND BRIDGE AT BREMEN.

Years.	Mean Annual Water-Mark. Meters.	Years.	Mean Annual Water-Mark. Meters.
1870	+0.96	1882	+0.69
1871	+1.30	1883	+0.38
1872	+0.58	1884	+0.56
1873	+0.36	1885	+0.25
1874	—0.13	1886	+0.06
1875	+0 42	1887	—0.17
1876	+0.82	1888	+0.43
1877	+0.86	1889	+0.16
1878	+0.86	1890	+0.09
1879	+1.11	1891	+0.24
1880	+0.96	1892	—0.52
1881	+0.77		
Sum	7.14	Sum	3.90
Mean	0.714	Mean	0.30

Comparing, first, the water surfaces, there can be estimated for the Upper Weser between Münden and Bremen, within shore lines, about 3 300 hectares (8 154.63 acres), that of the Lower Weser from Bremen to Bremerhaven at about 6 600 hectares (16 309.26 acres), and that of

TABLE No. 1

CALCULATION OF WATER VOLUMES AND VELOCITIES PRIOR TO THE IMPROVEMENT DURING ONE

Designation of the profile by places.	Water volume W. cu. m. cross-section F. sq. m. velocity v. m. E. = Ebb. Fl. = Flood.	I. Flood at Bremerhaven—hours before high water at Bremerhaven.						II. Ebb at Bremerhaven—ho Bremerha			
		5^{57}	5	4	3	2	1	1	2	3	4
1. Habenhausen	W. E.	320	320	296	296	296	296	296	296	296	296
	F. E.	296	296	320	320	320	320	320	320	320	320
	v. E.	0 92	0.92	0.92	0.92	0.92	0.92	0.92	0 92	0.92	0.92
2. Bremen (Grand Bridge)	W. E.	296	296	296	296	296	296	296	296	296	296
	F. E.	386	386	386	386	386	386	386	386	386	386
	v. E.	0.76	0.76	0 76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
3. Bremen (Safety Harbor)	W. E.	296	297	297	296	296	296	296	296	294	294
	F. E.	406	406	406	406	406	406	406	406	406	406
	v. E.	0.73	0.73	0.73	0.73	0 73	0.73	0.73	0 73	0.73	0.73
4. Hasenbüren	W. E.	304	308	305	300	296	300	289	274.	275	294
	F. E.	420	416	412	408	404	400	412	424	436	432
	v. E.	0.73	0.74	0.74	0 74	0.74	0.75	0.70	0.65	0.63	0.68
5. Vegesack	W. E.	326	333	325	312	304	272	176	199	293	329
	F. E.	565	542	519	496	473	460	527	604	660	657
	v. E.	0.58	0.62	0.62	0.63	0.64	0.60	0.33	0.3	0.43	0 50
6. Farge	W. E.	492	500	411	201	134_{40}	....	....	....	570	652
	W. Fl.	....	....	....	....	$_{20}52$	124	282	58	....	....
	F. E.	1 018	912	806	700	....	....	....	....	1 664	1 548
	F. Fl.	....	....	....	....	965	1 230	1 495	1 760	....	....
	v. E.	0.48	0.55	0.55	0 29	0.14	....	....	....	0.35	0.42
	v. Fl.	....	....	....	....	0 05	0.10	0.19	0.03	....	....
7. Brake	W. E.	1 402	1 065	54_{15}	....	....	....	....	828	2 614	2 571
	W. Fl.	....	(f. 45 M)	1 495	1 764	2 255	2 307	1 735	....	....	....
	F. E.	2 524	2 100	....	....	....	....	....	5 068	4 644	4 220
	F. Fl.	....	....	3 054	4 008	4 962	5 714	5 492	....	....	....
	v E.	0.56	0.51	0.01	....	....	....	....	0.16	0.57	0.61
	v Fl.	....	....	0.49	0.94	0.45	0.40	0.30	....	....	....
8. Bremerhaven	W. E.	191_{37}	....	....	....	....	....	306_{40}	6 529	10 324	9 24
	W. Fl.	$_{20}1\ 275$	2 569	10 223	8 656	8 013	6 256	$5\ 094_{20}$	....	....	....
	F. E.	....	....	....	....	....	....	....	10 970	10 056	9 14
	F. Fl.	6 460	7 728	8 996	10 264	11 532	12 800	11 884	....	....	....
	v. E.	0.03	....	....	....	....	....	0 03	0.60	1 02	1.0
	v. Fl.	0 19	0.33	1.13	0.84	0.70	0.50	0.43	....	....	....
9. Rothesand Lighthouse.	W. E.	....	....	....	....	....	....	....	....	....	....
	W. Fl.	....	....	....	....	....	....	....	....	....	....
	F. E.	....	....	....	....	....	....	....	....	....	....
	F. Fl.	....	....	....	....	....	....	....	....	....	....
	v. E.	....	....	....	....	....	....	....	....	....	....
	v. Fl.	....	....	....	....	....	....	....	....	....	....

REMARKS.—These certain hours during which, for a time, ebb as well as flood existed, are marked by the sm

TABLE No. 1.

EMENT DURING ONE TIDE, AT NORMAL FLOOD AND MEAN UPPER WATER = 0.73 BRE

Ebb at Bremerhaven—hours after high water at Bremerhaven.						Total amount of the water volume in cubic meters during—		Duration of the—		Mean-wat per se Cross-sec velocity pe
2	3	4	5	6	6²⁰	Flood.	Ebb.	Flood.	Ebb.	Flood.
								Seconds.	Seconds.	
296	296	296	296	296	296					
320	320	320	320	320	320		13 231 200		44 700	
0 92	0.92	0.92	0.92	0.92	0.92					
296	296	296	296	296	296					
386	386	386	386	386	386		13 231 200		44 700	
0.76	0.76	0.76	0.76	0.76	0.76					
296	294	294	296	297	298					
406	406	406	406	406	406		13 231 100		44 700	
0 73	0.73	0.73	0.73	0.73	0.73					
274.	275	294	307	305	307					
424	436	432	428	424	420		13 269 800		44 700	
0.65	0.63	0.68	0.70	0.72	0.73					
199	293	329	342	334	333					
604	660	657	634	611	588		13 262 800		44 700	
0.3	0.43	0 50	0.54	0.54	0.57					
	570	652	625	591	586		15 866 700		32 700	
58						1 7[illegible]2 800		12 000		144
	1 664	1 548	1 526	1 220	1 124					
1 760										1 220
	0.35	0.42	0.47	0.49	0.52					
0.03										0.12
828	2 614	2 571	2 126	1 790	1 703		47 272 900		27 600	
						33 056 100		17 100		1 933
5 068	4 644	4 220	3 796	3 372	2 948					
										4 830
0.16	0.57	0.61	0.56	0.55	0.57					
										0.40
6 529	10 324	9 243	7 569	5 653	3 830		149 133 600		24 300	
						126 223 800		20 000		6 678
10 970	10 056	9 142	8 228	7 314	6 460					
										11 500
0.60	1 02	1.01	0.92	0 77	0.60					
										0.58
							1 108 000 000		22 620	
						1 095 000 009		22 080		49 592
										140 900
										0.35

are marked by the small numbers which indicate minutes (') and follow or precede the numbers giving the

... Bremen Gauge.

...an-water volume per second. ...oss-section and ...ocity per second.		Mean-water volume per second. Cross-section and velocity per second, during a whole tide.
...lood.	Ebb.	
	296	296
	320	320
	0.92	0.92
	296	296
	386	386
	0.76	0.76
	296	296
	406	406
	0.73	0.73
	297	297
	418	418
	0.71	0.71
	297	297
	560	560
	0.52	0.52
144	485	400
1 220	1 230	1 230
0.12	0.40	0.33
1 933	1 713	1 800
4 830	3 230	3 900
0.40	0.53	0.46
6 678	6 137	6 400
11 500	7 890	9 700
0.58	0.78	0.66
47 592	48 983	49 300
40 900	130 400	136 300
0.35	0.38	0.36

...ng the water volumes.

TABLE No. 3.

Comparisons of the Velocities and Volumes of the Upper Weser at Tide Limits.

Water-mark on the gauge on the Grand Bridge at Bremen.	Velocities in meters per second.						Cross-section. = F			Water volume. = W			Remarks.
	The Big Weser.		The Little Weser.		The whole stream.		The Big Weser.	The Little Weser.	The whole stream.	The Big Weser.	The Little Weser.	The whole stream.	
	On the surface. v.	Mean. vm.	On the surface. v.	Mean. vm.	On the surface. v.	Mean. vm.							
m.	m.	m.	m.	m.	m.	m.	sq. m.	sq. m.	sq. m.	cu. m.	cu. m.	cu. m.	
0	0.67	0.52	0	0	0 67	0.52	293	....	293	150	0	150	
0.73	0.96	0.76	0	0	0.96	0.76	387	....	387	296	0	296	0.73 was the mean annual water-mark from 1870 to 1879.
1	1.04	0.81	0	0	1.04	0.81	418	....	418	340	0	340	For the readings 1 to 5 the respective factors were obtained from the curves of the graphical plotting.
2	1.35	1.07	0	0	1.35	1 07	543	....	543	580	0	580	
3	1.65	1.30	0	0	1 65	1.30	668	....	668	900	0	900	
4	1.43	1.18	1 32	1.06	1.40	1.13	810	510	1 320	930	540	1 470	
5	1 90	1.56	2.13	1 76	2.09	1.17	940	583	1 523	1 465	1 035	2 500	
5 22	2.02	1.69	2 15	1.79	2.10	1.72	966	600	1 566	1 620	1 070	2 690	Highest water-mark, December 27, 1880.
5.54	2.28	2.41	2.00	1.90	2.24	1.94	1 004	620	1 624	1 910	1 240	3 150	Highest water-mark, March 13th, 1881.

To the maximum of 3 150 cu. m., measured directly in the Weser itself, must be added an approximate amount of 1 000 cu. m. for a lateral overflow on the left bank above Bremen, and which only found its way back into the Weser through the Ochtum Valley.

the lowest, a tide funnel extending from Bremerhaven to the mouth proper, at 53 000 hectares (130 968.30 acres). The water surface of the tidal section therefore exceeds considerably that of the upper river, the area of which, including its tributaries, may be estimated at from 6 000 to 7 000 hectares (14 826 to 17 297 acres). The volume of water moving in the tidal section exceeds to a far greater extent that which occurs in the upper river. For a mean volume of 150 cu. m. per second of summer flow at Bremen, there are at Bremerhaven, 6 400 cu. m. per second which form the mean volume of a whole tide, and at the mouth, 56 000 cu. m.

The greatest flow of the upper river water, which amounts at Bremen to about 4 000 cu. m., is opposed, however, at Bremerhaven, when the flood tide is 1.5 m. above the ordinary high water-mark, by a mean volume of 12 000 cu. m., and at the mouth by at least 100 000 cu. m. If, instead of the mean movement in the tidal section, we consider the maximum movement at half ebb and flood tide, then these figures will be nearly doubled. In accordance with these conditions, the influence of the upper water ceases to be felt at Brake.

As already stated, the arithmetical mean of the daily readings of the river gauge at Bremen was obtained from observations taken during the 10 years between 1870 and 1879, and was established as 0.714 m. on the principal gauge at Bremen. A higher level than 0.714 m. occurred on an average during these 10 years on 147.6 days, and a lower level on 217.6 days per year.

The water level stood at nearly uniform elevation in Bremen for a considerable length of time, since during 82.4 days it ranged from —0.5 to 0, and for 77.5 days from 0 to 0.5 annually. The so-called normal or ordinary level, which the water in any year was as often above as below, was 0.5 m. The duration of high upper river water rapidly decreases with its height, so that a reading of 4 m. occurred only during 1.9 days in a year. It is again emphasized that since the improvements of the Lower Weser have been commenced, all the water levels at Bremen show a lowering, as compared with earlier observations. As the improvements have not yet been completed, the old conditions are used as the basis for the purposes of this paper.

Aside from these changes, it is only in the upper part of the tidal section that the influence of the upper water is appreciably perceptible, and it is also observed that near the tide limits at Bremen the effect

of the upper water depends mostly on the mean annual water level, while the separate tidal phenomena in the upper part of the tidal section can best be recognized at lowest water. Thus, while before the improvement the water level stood at 0 at Bremen, during the half year comprising the summer months the mean high-tide reading was 0.15 m.; whereas, during 1892, after the summer water level had in the mean time lowered to —1.06 m., the mean high-tide reading was 0.69 m. Formerly the ordinary tide limit was a little above Bremen; since the improvement, however, it has moved up stream about 7 km., and will probably advance still farther up.

Table No. 2 shows that the mean-water level at and above Bremen, from 1880 to 1891, was, on an average, lower than during the period from 1870 to 1879. The mean annual water level was particularly low in the years 1886, 1887 and 1890.

A solid ice crust, which does not occur at Bremen every year because of the nearness of the sea, and which rarely extends farther down stream than Brake, hinders the tide movement in the upper tidal section; on the other hand, high tides will break up any ice crust below Vegesack and cause it to be carried down stream.

Of all the matter brought down from above to the beginning of the tidal section, the finer material settles only in the lower portions thereof, in branches and protected bays, along with the silt which is washed up stream from the sea, while the coarser sand and gravel settle sooner in many places, principally in the stretch between Farge and Brake. Large gravel is deposited only in deep channels where the strongest currents prevail.

For a full understanding of the action of the tide wave in the Lower Weser, it must be observed from the sea. If the directions of the Jade, Weser and Elbe, at their lowest parts, where they discharge into the sea, were produced, they would meet at a very sharp angle at Helgoland (see Plate I). It is possible to follow their beds and still more so their currents to within 30 to 40 km. of Helgoland. The tide waves of the North Sea approach Helgoland, and hence also the confluence of these external river currents, from a northwesterly direction; therefore the same tide wave throws one part into the Weser and the immediate adjoining part into the Jade and into the Elbe, so that in relation to the tide these rivers can be considered as branches of one trunk.

It is highly interesting to note that, based upon a number of tide curves for the year 1889, at Helgoland a mean tide difference of only 1.84 m. was found to occur; whereas, according to the Hydrographic Bureau, such difference is 3.1 m. at Cuxhaven, 3.3 m. at Bremerhaven, and even 3.8 m. at Wilhelmshaven. It must be observed that on account of the comparatively short period during which careful measurements have been taken, particularly with self-registering gauges, all these statements are not to be regarded as exact. These great differences can be explained by allowing for the position of the observation points, and the variation in the shape of the river mouths. Cuxhaven being the most seaward, lying on the extreme border of the tide funnel, and having the longest river behind it, of course receives the least obstructed tide wave. More favorable conditions for heavy piling up of the tide exist at Bremerhaven and even more so at Wilhelmshaven.

While Helgoland (see Plate I) is virtually free on all sides, a marked funnel formation is noticeable at the first point of observation, lying 39 km. landwards, which is the lighthouse on the "Rothensand," near the mouth of the Weser; the action, however, affects only sand bars lying deep under low-water level, and for this reason the tide gains 0.84 m. in range from Helgoland to that point, that is, changing from 1.84 to 2.68 m.

From Rothensand lighthouse, for a farther distance of 45 km. landwards to Bremerhaven, where, as previously stated, a tide difference of 3.3 m. is found, another increase of 0.62 m. in tide elevation takes place. The difference in harbor time of the last two places is one hour and twenty-eight minutes, from which is deduced a velocity for the high-tide crest of 8.52 m. per second.

At Bremerhaven the tide elevation reaches its maximum, while it gradually decreases up stream because of still existing irregularities of the river-bed, and disappears entirely about 7 km. above Bremen. It is evident that with the advancing improvements all tide conditions above Bremerhaven must change, and upon this depends the success and the permanence of the improvement works. The low-water surface, especially of the upper stretch, will be considerably lower; for instance, at Vegesack it will be lowered about 1 m., while high-water level will be changed very little. At the same time the progressive velocity of the tide wave will increase materially, so that the increased space contained between high and low water will be more quickly

filled by the up-running tide wave. This increase is clearly shown by the hourly water-level curves noted before and after the improvements were made (see Plate IV).

II. Principles Underlying the Improvements Projected by the Writer.

The object of the improvement of the Lower Weser is the making of a uniform and deep channel in the entire upper tide basin above Bremerhaven, and the maintenance of the created conditions by means of the increased and regulated current power, and with little other assistance. The means to accomplish this object is the formation of a regular river-bed, gradually narrowing up stream in accordance with positive laws, so as to impede as little as possible the free movement of the water.

To gain this it is necessary to do away with all sharp bends and irregularities of the channel, and especially all breaking or splitting of the stream, as these always oppose the movement of the water. In order to fix the bed, no projecting works, such as groins or dikes, should be constructed, as they unavoidably set back the water up stream.

Although the back-water or rise produced by a single groin is small, yet, by adding a larger number of these, it attains a considerable magnitude. Such back-water is, however, equivalent to a corresponding decrease of flood-tide volume, and tends to weaken the effect of the tide wave in that particular neighborhood. The less impeded the tide wave is at every point, the larger will be the water volume flowing up stream with the flood tide, and in like manner the current power will be increased as well with the incoming tide as with the deeper outgoing ebb.

The increase of current power is proportional to $\frac{m\,v^2}{2}$, that is, it is proportional to one-half the product of the water mass into the square of the velocity; and this increase must be considered as the most important principle in the improvement of a river's tidal channel, for with it the ability of a river to move sediment, and hence its power to deepen and maintain its bed, also increases.

It was upon these principles that the project for the improvement of the Lower Weser was based. In the first place, it was necessary to

fix the conditions as they actually existed before the commencement of the improvement. To this end all bottom contours, which had been obtained from carefully made soundings, were plotted on existing maps to a scale of 1 : 4 000 and at 1 m. apart. Further, the water surface for every hour was plotted in profile, as it was obtained from the graphical records of the existing self-registering gauges, thus obtaining the so-called tide curves.

By means of the distance between these water-surface curves and the corresponding areas of the water surface, the volumes of water passing hourly a given point of observation were computed, and from the volumes and the corresponding cross-sections the mean velocities for the stated intervals of time were determined. The volumes, cross-sections and velocities at each gauge station were then graphically plotted, and from these plots mean values were obtained.

In this way the important actual conditions which existed prior to the commencement of the works were ascertained, and by their use the analogous values which might be expected to follow the improvements were determined in a speculative way. To do this, however, it was necessary, in the first place, to decide upon the mean high and low water lines which could be expected after the completion of the improvement. These were fixed by carefully considering all possible influences, as well as by preliminary computations and estimates, and then making them the basis of future calculations. The high water-line showed only an insignificant rise at the upper end of the stretch proposed to be improved, while the low water-line showed a considerable lowering in spite of the fact that the most favorable assumptions were studiously avoided.

The approximate form of the future river-bed having thus been decided upon, the entire tide intervals of the different points, as obtained from the high and low water-lines, were divided into an equal number of parts. From the flood-tide curve for Bremerhaven, for which only an insignificant change was presumed to result from the improvements and from the progressive velocities (calculated by Green's formula $C = \sqrt{2 g t}$) of different points of the ascending half of the tide wave, the time changes for the corresponding subdivisions of the tide curves of the different points as compared with Bremerhaven were ascertained, and, therefore, also the absolute times of the water levels corresponding to those subdivisions, so that the ascending half

of the tide wave could be plotted through these points. In order to ascertain also the descending half of the tide curves, there were selected out of a large number of actually measured tide curves those which showed in their ascending halves the greatest conformity with the newly plotted flood-tide curves, and from these the still unknown ebb-tide curves were then taken.

The next step taken was the fixing of the water-surface curves of the newly determined volumes and velocities. By means of diagrams, comparisons and the calculated surface slope of the future low water, both the assumed low water-line and the assumed form of the channel were modified until a satisfactory agreement of all results was finally obtained.

Particular value was placed on the proper development of the cross-sections. The latter, as shown on Plate III, Fig. 2, consist of two parts which differ materially, viz., the deep central part, which forms the low-water channel and serves as the navigable water-way, and the shallow side parts, the bottoms of which are about on a level with the low water-line. While the last-mentioned parts are capable of containing a large volume of water, the velocity therein will be insignificant on account of the shallow depth, so that only a small portion of the current power will there be used up. Nearly the whole of the current power is therefore available for the low-water section, to which the water movement is almost exclusively confined; whereas, the side portions during flood tide are filled from the middle section, and empty themselves back into it during ebb tide, thus operating like elongated flushing basins (spülbassins).

The low-water channel is therefore protected as much as possible against the deposition of sediment, while the water which flows from the central channel over into the adjacent side channels during flood tide suffers a loss of velocity and causes deposits therein. In order to produce the described cross-section, low guiding dikes were made of sunken fascines, so placed as to cover in some localities both sides of the low-water channel and only the concave side in others, in order to provide a safe and unchangeable boundary. These guide works reach only to low water, and are, therefore, very little exposed to the action of currents or ice.

The filling in of the spaces back of the dikes is made partially by direct filling with dredged material; while for future deposits from the

river itself, there is still remaining along the improved channel sufficient space to contain 19 000 000 cu. m. of material.

Between the guide dikes there is just sufficient cross-sectional area to permit the water volumes, which are present shortly before and after low tide, to move without special difficulty, so that no "serpentining" of the water shall occur. For this reason there was no hesitation about laying out the axis of the river for long distances in a straight or nearly straight line, since in the author's opinion there is no necessity for the curving of a river if the bed is properly formed for the smallest amount of flow.

As shown in Plate II and Plate III, the low-water channel which is enclosed by the guide dikes gradually widens in going down stream, but not uniformly; furthermore, the width of the high-water channel also increases continually in going down stream, excepting at Brake and Nordenham, where two contractions exist, which could only be avoided by incurring unreasonable expense. As the side portions of the improved channel have only a limited share in the conveyance of the water, these contractions are very unimportant. At the designated points, these contractions even operate to advantage, in consequence of the admissible enlargement of the low-water section in the harbor fronts of Brake and Nordenham. The high-water channel is not arranged symmetrically with respect to the low-water section, because a symmetrical arrangement would have required a double amount of excavation on account of the irregular shape of the old river-bed.

It was necessary, without regard to cost, to do away with the most prominent faults of the old river-bed, such as the large splits between Vegesack, Elsfleth and Brake, and also those at Strohausen and Dedesdorf. At the Strohausen Plate the improvement was made by shutting off the branch which was at the time much the larger, but also the most curved, in favor of the shallower but straighter branch.

In estimating the cost, it was of the utmost importance to know how much material would have to be removed either by dredging or by current action. Although the execution of the improvement was so designed as to provide for cutting off the side channels first, both in order to secure the greatest aid from the current to the main channel as well as to deposit in the most favorable manner the material dredged from the main channel, still it was to be presumed that much more dredging would here be necessary than in the improve-

ment of upper river channels, because in a tidal channel a stronger current can be created only by first removing the shoals and bars. While it may not appear impossible to accomplish the improvement of a tidal channel by means of correctional structures such as dams and dikes alone, yet the result would in most cases be effected much too slowly and would often be rendered doubtful on account of accidental conditions such as spring tides, storm floods, ice, etc. On the other hand, it is often feasible to leave to the current the removal of a not insignificant amount of material, especially of the lighter kind ; and for that reason, of the total of 55 000 000 cu. m. of material to be removed from the Lower Weser, it was assumed that 31 000 000 cu. m. would have to be removed by dredging and digging, and 24 000 000 cu. m. by the ebb and flood currents.

It is self-evident that both in the section under improvement as well as in that below it, sufficiently large areas must exist on which the scoured material can be deposited without damage. Furthermore, it is necessary to secure an increase of current below the portion under improvement by augmenting the volume of water moving in the latter ; otherwise there would be a deterioration of the channel, because the sediment carried along would be deposited there in greater quantity. In the Lower Weser it was calculated that the increase of water volume passing Bremerhaven amounts to fully one-sixth more than the original volume, so that below Bremerhaven an improvement of the river channel will also be attained, inasmuch as the suspended material will not appreciably increase the height of the extensive lateral shoals.

Although the Lower Weser between Bremen and Bremerhaven had previously been partially improved at the sole expense of the State of Bremen, it was not until 1891 that the States of Prussia, Oldenburg and Bremen adopted, as a joint undertaking, the project of the author for the improvement of the Outer Weser, that is, the portion of the Weser below Bremerhaven. This had for its object the removal of a bar which was the result of a split in the river which had existed for 30 years and caused the formation of a continually growing shoal about 7 km. in length.

This improvement consists essentially in the construction of a guide dike about 6 km. long, commencing at a projecting angle near Blexen, and which will be extended down stream in as straight a line as practicable. Whether and to what extent it may be connected by

TABLE No. 4.

COMPARISONS OF THE WATER VOLUMES, VELOCITIES (IN THE MEAN PER SECOND DURING ONE TIDE) OF NORMAL, HIGH AND LOW TIDE BEFORE AND AFTER THE IMPROVEMENTS WITH REFERENCE TO THE DIFFERENT HEIGHTS OF THE HIGH WATER-MARKS.

Designation of the profile by places.	Mean water volume per second, cu. m. Cross-section and velocity per second during the whole tide.	Averaged Tides.				Various actual Tides.				
		I. Before the improvement.		II. After the improvement.		5. High tide October 18th, 1879, and low upper water = 0. o. m. Bremen gauge.	6. Normal tide on February 21st, 1879, and high upper water = 3.0 m. Bremen gauge.	7. High tide on February 21st, 1879, and high upper water = 3.0 m. Bremen gauge.	8. Low tide March 17th, 1879, and high upper water = 0.3 m. Bremen gauge.	9. Normal tide and low upper water = 0. m. Bremen gauge.
		1. Normal tide and mean upper water = 0 73 m. Bremen gauge.	2. Normal tide and low upper water = 0. m. on the Bremen gauge.	3. Normal tide and mean upper water = 0.73 m. Bremen gauge.	4. Normal tide on low upper water = 0. m. Bremen gauge.					
1. Habenhausen	W.	296	150	296	150	135	900	900	900	150
	F.	320	230	406	310	210	630	630	630	230
	v.	0.92	0.65	0.73	0.49	0.64	1.43	1.43	1.43	0.65
2. Bremen	W.	296	150	297	150	127	900	900	900	150
(Grand Bridge)	F.	386	280	540	480	......	......	......	.....	280
	v.	0.76	0.54	0.55	0.40	......	......	......	......	0.54
3. Bremen	W.	296	150	297	150	124	900	900	900	151
(Safety Harbor)	F.	406	325	580	460	330	670	670	670	325
	v.	0.73	0.46	0.50	0.33	0 38	1.34	1.34	1.34	0.46
4. Hasenburen	W.	297	150	301	150	135	900	900	900	156
	F.	418	350	590	510	400	620	620	628	350
	v.	0.71	0.43	0.51	0 31	0.34	1.45	1.45	1 45	0.44
5. Vegesack	W.	297	161	346	330	204	900	898	900	164
	F.	560	505	630	570	600	760	780	700	505
	v.	0.52	0.32	0.56	0 53	0.34	1.19	1,15	1.28	0.32
6. Farge	W.	400	393	990	990	640	896	872	907	377
	F.	1 230	1 200	1 340	1 340	1 450	1 630	1 800	1 450	1 200
	v.	0.33	0 33	0 73	0.73	0.44	0.55	0.49	0.63	0.32
7. Brake	W.	1 800	1 807	2 670	2 700	2 456	1 462	1 894	1 298	1 865
	F.	3 900	3 900	3 390	3 390	4 700	4 000	4 160	3 730	3 900
	v.	0.46	0 47	0.80	0.80	0.53	0.37	0.45	0.35	0.48
8. Bremerhaven	W.	6 400	6 416	7 510	7 600	9 217	6 323	7 236	5 173	6 542
	F.	9 700	9 700	8 690	8690	11 400	9 400	9 850	9 100	9 700
	v.	0.66	0.66	0.86	0.87	0.81	0.67	0.74	0.56	0.67

cross-dikes with the left bank, which is a sand field lying between high and low water, is not yet determined, because some small vessels have a certain interest in maintaining an open channel there.

Soon after 5 km. of the dike had been constructed during the period from April to September, 1891, an average increase in depth of 0.3 m. was observed over about 1 sq. km. of the surface of the bar, and six months afterwards the increase in depth was 0.5 m. The increase in depth of the channel proper, in the fall of 1892, was 2½ m. To assist the action of the current upon this bar, dredging was done during the summer of 1892, which resulted very favorably, for while formerly in the neighborhood of the bar the navigable water was confined to a narrow channel only 100 m. wide, the width is at present 500 m.

III. Execution of the Improvement.

In order to secure the indispensable uniformity in the execution of the work, the chief technical management is vested in the writer, under whom is Bau-Inspector Bücking as first assistant, in addition to several engineers (baumeister), and about eight assistant engineers. The subordinates consist of several overseers, clerks, and a large number of dredge and boat captains and steam engineers. All dredging work is done by our own forces, while the improvement works are performed by contract. For the dredging, therefore, it was necessary to obtain a large number of dredges, transport vessels and other apparatus, of which a schedule is given in Table No. 5.

TABLE No. 5.

Schedule of Apparatus and Vessels Obtained for the Improvement of the Lower Weser.

Number.	Class.	Dimensions.				Greatest dredging depth. Meter.	Buckets.		Hourly capacity. Cubic meter.	Machines.	
		Length. Meter.	Width. Meter.	Depth. Meter.	Draft. Meter.		Contents Cubic meter.	Number.		Number.	Indicated Horse-Power.
A.—Bucket Dredgers for Working in the Open River Channel.											
1	A	35.2	7.0	2.9	1.25	7	0.25	34	120	1	70
3	A	34	6.85	2.8	1 25	7	0.20	33	120	1	70
1	A	37	6.85	2.8	1.25	9	0.18	37	120	1	70
1	B	32.8	9.0	3.3	1.50	8	0.30	35	180	1	170
2	C	42	8.8	3.2	2.00	9	0.44	35	250	1	200
1	F	47	7.1	2.5	0.86	4.6	....	20	....	1	20

TABLE No. 5—(*Continued*).

Number.	Class or Name.	Dimensions.				Rate of speed. Knots.	Capacity.
		Length. Meter.	Width. Meter.	Depth. Meter.	Draft. Meter.		

B.—Secondary Dredgers.

Apparatus for removing material dredged out of the river channel.

I. Pumping Dredgers.

1	FG	43	6.80	4.0	3.0	10	....	......	70-100	1	300
1	FG	24.4	6.80	3.50	1.60	7	....	......	150	1	320

II. Bucket Dredger, with Suction Dredger.

2	F	33	6.10	2.58	1.2	7	0.317	32	150	2	90
2	G	24.4	6.80	3.50	1.6	....	....	......	150	1	320
1	G	25	8.5	2.4	1.5	....	....	......	80	1	150

III. Scow Dredger (Bucket Chain Dredger).

This lifts the dredged material out of the scow and delivers it into railroad cars.

C.—Vessels for Transporting the Dredged Material.

I. Steam Scows.

8	D....................	36	6.8	2.20	1.5	6	100
4	D....................	35	6.8	2.40	1.5	6	100
2	D....................	35	7.0	2.35	1.5	6	100
4	E....................	45	8.0	3.0	2.0	6	200
4	E....................	45	7.9	3.0	2.0	6	200

II. Tugs and Common Scows.

2	Nord u. Sud............	20	5	2.075	1.5	8	
2	Ost u. West............	17.2	3.6	2.1	1.4	8	
1	Pony..................	15.5	3.4	1.6	1.4	8	
12	Without bottom gates..	21	4.6	1.6	1.15	....	35 cu. m.
48	With " " ..	22	4 8	1.8	1.20	....	40 "

D.—Inspection Steamers and Launches.

1	Tide..................	26	4.6	2.55	1.4	10	
1	Dünung................	17.5	3.8	2.1	1.5	8	
2	Woge u. Bore..........	13	3.1	1.6	1.2	8	
2	Stau u. Welle..........	13	3.1	1.6	1	8	
2	Ebbe u. Fluth..........	11	2.2	1.2	1	8	
1	Vipp..................	9.5	2.4	1.4	1	$6\frac{1}{2}$	
1	Spring................	9.3	2.2	1.21	1	$6\frac{1}{2}$	

E.—Sailing Vessels.

1	Kaus..................	Sailing yacht.					

F.—Coal Hulks.

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The greater part of all the apparatus was provided at the outset of the work, with the exception of the secondary dredges (pump dredges and flushing machines), as the latter were particularly necessary only after the filling up of the lateral branches of the river which were to be cut off, and which gradually became inaccessible to the dumping scows. Active dredging is stopped only in December and January, during which months all necessary repairs are thoroughly done; during the remainder of the time the work progresses uninterruptedly day and night.

To accomplish this, the vessels and dredges are provided with double crews. All dredgers have electric lights, and on the water where the scows travel, small light-buoys are placed. These are cheaply constructed by fixing in two barrels a wooden frame on the top of which a lantern is carried in a light iron stand. The dredging work in the actual river channel is done with bucket dredges of the classes designated "A, B and C" (see Table No. 5). The dredged material is carried by 22 steam scows and 60 ordinary scows directly to the dumping places, if possible, and there emptied through the bottom valves of the scows; but where, as above mentioned, these places become too shallow, the scows cannot be used during low water, because they are liable to run aground or to lose valuable time waiting for high water.

In order to remove the dredged material cheaply and without losing time in spite of this latter difficulty, there were introduced in the third year, 1890, two kinds of secondary dredgers (pumping or suction dredges and flushing machines). These are placed at convenient points along the bank, and relift the dredged stuff left there by the scows, and flush it away through flexible lines of pipe to a distance of several hundred (400 to 500) meters. The removal of the material, mixed with water in the proportion of 1 to 9, is accomplished in both kinds of dredgers by means of a large centrifugal pump worked with a horizontal shaft. The lifting of the material by the pump dredgers is accomplished by the same kind of centrifugal pump in connection with a suction pipe reaching to the bottom; whereas, in the other kind of secondary dredgers called flushing machines, this is accomplished by a chain bucket dredge attached temporarily to a scow carrying the centrifugal pump and into which the dredged material is emptied.

The chain bucket dredge can also work independently. Although this second kind of dredging apparatus is more expensive in first cost, and appears more complicated, yet it works cheaper than the first kind. The reason for this lies in the impossibility to work upon uneven ground with the suction pipe so uniformly as to avoid sucking up too much water. The work of the bucket dredger is much more uniform, because it requires only light buckets and chains on account of the thoroughly loose condition of the previously dumped material, and the efficiency of the centrifugal pump, which is by far the more powerful part of the combined apparatus, is materially increased. These flushing machines have also been used for actual dredging close along the shore, especially in lateral branches where the dredged stuff could be disposed of in the immediate neighborhood.

One of the greatest difficulties connected with the operation of the suction dredges was to keep united that portion of the piping which floats between the dredge whose position is continually changing, and that portion which lies fixed on the shore. While for the latter portion plain, straight, flanged sheet-iron pipes, 3 mm. thick, 0.50 m. in clear diameter, and 6 m. long, with some elbows were found sufficient, it was necessary in the other portion to make the tubing very flexible by special joints, and also to keep it floating on the continually changing water surface. The necessary flexibility was obtained after repeated experiments by the introduction of short connecting pieces between the separate pipes. These connecting pieces consist of a strong leather hose which is protected against exterior damage by an armor of steel wire netting with iron stiffening rings. The tubes are floated on pairs of sheet-iron cylinders of the length of the straight pipes, said cylinders being connected by wooden frames. At the ends of the wooden frames are iron bows to serve as bumpers, so that the pliable joints cannot be bent too much by wave motion, etc. At low water some of the tubes which float during high water rest upon the sloping shore.

The further the improvement progresses, the more important the operation of all these suction dredgers become, because of the fact that the water diminishes continually in depth over the area to be filled.

The acquisition of a seaworthy suction dredge for the improvement of the Outer Weser is not necessary for the present, for, notwithstanding the superiority of such apparatus, the work there which is

insignificant, can be done in favorable weather by the large bucket dredges.

Since the beginning of the improvement works the following quantities have been removed from the river channel during the respective years:

	Cubic Meters.		Cubic Meters.
1887	170 000	1890	4 100 000
1888	1 700 000	1891	4 270 000
1889	3 750 000	1892	3 480 000
Total			17 470 000

The cost for dredging and disposing together, including the secondary work done by the suction apparatus during the years 1890 and 1891, amounts per cubic meter to 0.48 mark (about 11.4 cents).* This includes:

(*a*) For a sinking fund, 10% on the first cost and maintenance, in round figures, 0.11 mark.

(*b*) The entire cost of administration, in round figures, 0.08 mark.

The actual cost of dredging and disposal of the material is therefore only about 0.29 mark per cubic meter. The cost per cubic meter of dredging and disposal by the suction dredges in the year 1891 was, exclusive of sinking fund, about 0.16 mark; including sinking fund, about 0.25 mark.

The construction of the improvement works, that is, the guide dikes as well as the closing dams, was vigorously pushed during the first few years in order to gain all possible co-operation of the current in the formation of the channel. All these works are made of brush which was worked up for the greater part into mats. In the construction of the guide dike in the Outer Weser, some of these mats had to be transported 10 km., because there was no suitable working place obtainable near the site of the dikes. The transportation of the mats, which are from 10 to 15 m. wide, 20 to 30 m. long by about 1 m. thick, and draw scant 0.5 m. depth of water, offered no difficulty in towing by small tugboats. These large bodies are somewhat elastic and therefore adjust themselves in some degree to the form of the river bottom; they are placed over the designated localities between anchored vessels, and during quiescent water are loaded with stones from the vessels and guided exactly into place by means of ropes.

* 1 mark = 23.8 cents.

The lower strata of mats in the dikes are on an average 2 m. wider than the next following, so that the dike obtains a slope of 1 to 1 on both sides. The uppermost layers are usually only 4 to 5 m. wide. To equalize the irregularities of the surfaces of the mats, continuous layers of packwork with strong interlaced partitions or borders are made, and the spaces between the latter are filled in with quarry stones as closely as possible.

As already mentioned, the guide dike extends on an average only about 0.10 to 0.20 m. above low water, with the exception of the ends joining the higher shores, where they rise to about half-tide. This low position admits of the free motion of the tide water, and protects the dike against the injurious attack of the waves, and especially of the ice cakes. The particularly heavy ice movement of 1891 did no damage to any part of the works, which would hardly have been the case had they been constructed of stones only. On account of their noticeably advantageous influence, which was manifested during the progress of the improvement, more dike works were built than was originally contemplated.

Notwithstanding that about 450 000 cu. m. of fascines were used yearly from 1889 to 1891, and that a portion or the material for them had to be transported over 100 km., still there was no trouble to obtain it from the competing contractors. From the beginning of the improvement up to December 31st, 1892, the following materials were purchased for the making of mats: 2 100 000 cu. m. brush, 6 600 000 lin. m. of stakes of 6 cm. in mean diameter, 145 000 bundles of willow twigs (1 bundle = 100 pieces), 6 000 cu. m. of fence brush, 85 000 cu. m. of ballast stones, 370 000 kg. galvanized iron wire of 3.1 to 5 mm. thickness, and 132 000 kg. ropework. Out of these materials were made, in round numbers, 1 050 000 cu. m. of finished mats or packwork. From this it will be seen that there was used for 1 cu. m. of finished work 2 cu. m. of brush, 6.2 lin. m. of stakes, 0.14 bundle willow twigs, 0.0057 cu. m. of fence brush, 0.081 cu. m. ballast stone, 0.32 kg. of galvanized iron wire, and 0.12 kg. of ropework.

The cost of material delivered on the site was on an average as follows:

One and six-tenths marks per cubic meter brush, 3.5 marks per 100 linear meter stakes, 3.8 marks per 100 bundles willow twigs, 3.50 marks per cubic meter fence brush, 7.55 marks per cubic meter ballast stone,

24 marks per 100 kg. of galvanized iron wire, and 61 marks per 100 kg. of ropework. The cost, therefore, of material in 1 cu. m. of finished work was 4.2 marks, to which must be added 2 to 3 marks for labor; so that the cost of 1 cu. m. of finished work varies from 6 to 7 marks.

A few additional remarks concerning the improvement of the Lower Weser, and the peculiar attendant conditions, may also be admissible here.

The order in which the works followed each other made it necessary to harmonize the requirements of navigation with the theoretical principles of the improvement. In accordance with the latter, it would doubtless have been more advantageous to have commenced the works at the lower end and gradually progressed up stream. As, however, for reasons of policy, the free and Hanse town Bremen was obliged to build the free harbor below the city during the years 1885 to 1888, at a cost of about 30 000 000 marks, and could only commence the improvement of the Lower Weser in 1887, it was desirable to admit larger ocean vessels to the finished harbor as soon as possible; otherwise both the interest on the outlay for the harbor, and the advantages gained by the attractions of trade to the town, would have been sacrificed for some years. With these fundamental principles in view, the improvement works were so managed that from 1888 to 1892 the channel depth to Bremen was increased from 2.75 to 4.70 m. at ordinary high tide and mean river discharge; and as a consequence, 620 000 tons of arrivals and departures were already registered at the harbor of Bremen in 1891.

Another purely technical question is, whether the closing of the larger side branches should be done quickly or slowly. In accordance with the main object of the improvement, which was the attainment of the greatest possible water movement, it was essential not to block up a side branch appreciably more than the main branch could at the same time be enlarged, especially if the latter was small in the beginning. In that case, however, the progress of the entire work would be too slow. Where it is required to enlarge the main branch 1 000 sq. m. in cross-section, every kilometer of its length will furnish 1 000 000 cu. m. of material to be removed. If the split of the channel in question is several kilometers long, there results an equal number of 1 000 000 cu. m., the greater part of which would have to

be dredged to gain the required object. To do this would require several years, even with the use of a most elaborate dredging plant.

On the other hand, it is possible, in a few months to shut off a large side branch by the aid of the previously described methods, that is to say, by the construction of guide dikes above and below and a dam in the middle portion so that at the time of low water only a small quantity will flow through, while these dams being built low offer comparatively little impediment to the flow of the rising tide. By these means a powerful co-operation of the current power is obtained in the main branch, principally at the time of low water, whether it be ebb or flood. The result of this is that the main branch is rapidly deepened by the increased current action, and a portion of the scoured material which is conveyed beyond the upper and lower points of separation is carried into the side branch by the changing currents; and as the velocities are there diminished by the dikes, the greater part of the sedimentary matter is deposited.

There is opposed, however, to these advantages an unavoidable disadvantage from the fact that the low-water surface above the split in question is kept at a relatively high elevation until the main branch has become widened to such an extent that it alone, or in conjunction with the remainder of the side branch, can carry off as much water at the time of low water as both branches could before the improvements. This disadvantage is, however, temporary and must be endured for the sake of attaining the more important advantages.

Thus the low-water surface above the Strohausen Plate rose about 0.20 m. during the years 1889 to 1891 in consequence of the contractions made in the left branch. This rise, however, reached its greatest height in 1891, and will probably disappear about the beginning of 1893, because an appreciable deepening in the right-hand branch has occurred in the mean time, also because the dredgings there are being pushed with special vigor. Between 5 000 000 and 6 000 000 cu. m. of material were scoured into the left branch, and have been permanently deposited therein, which would not have been attained so rapidly or so cheaply had not such vigorous changes of the old conditions been made by means of the guide dikes and cross dams. Such a local raising of the low-water surface, moreover, does not necessarily cause a decreased water movement above. It is even possible to increase the same if the improvement works are carried on with suf-

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FRANZIUS ON IMPROVEMENT OF THE
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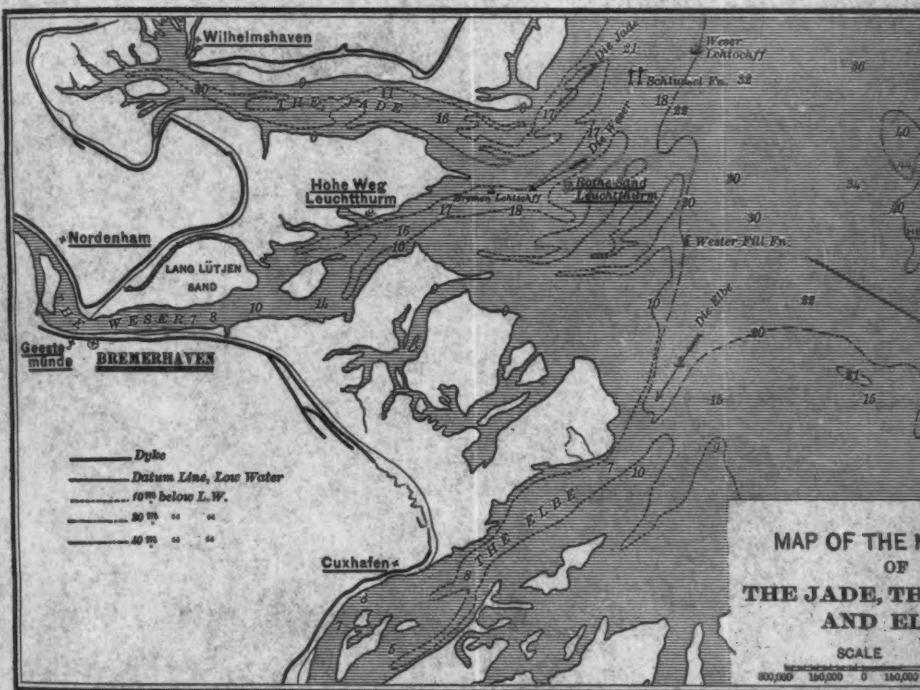

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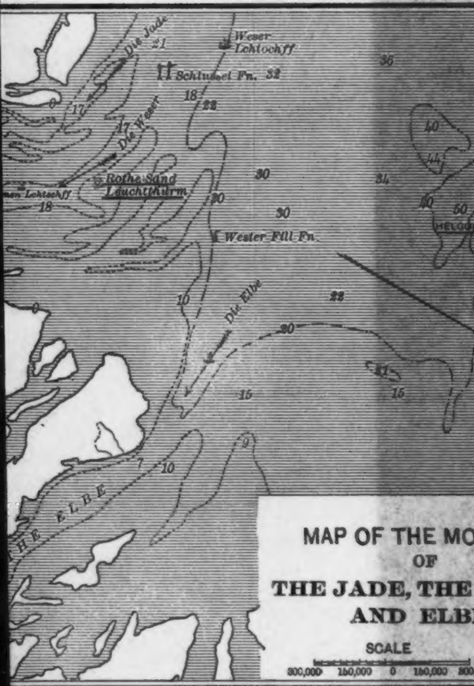

607.
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THE LOWER WESER.

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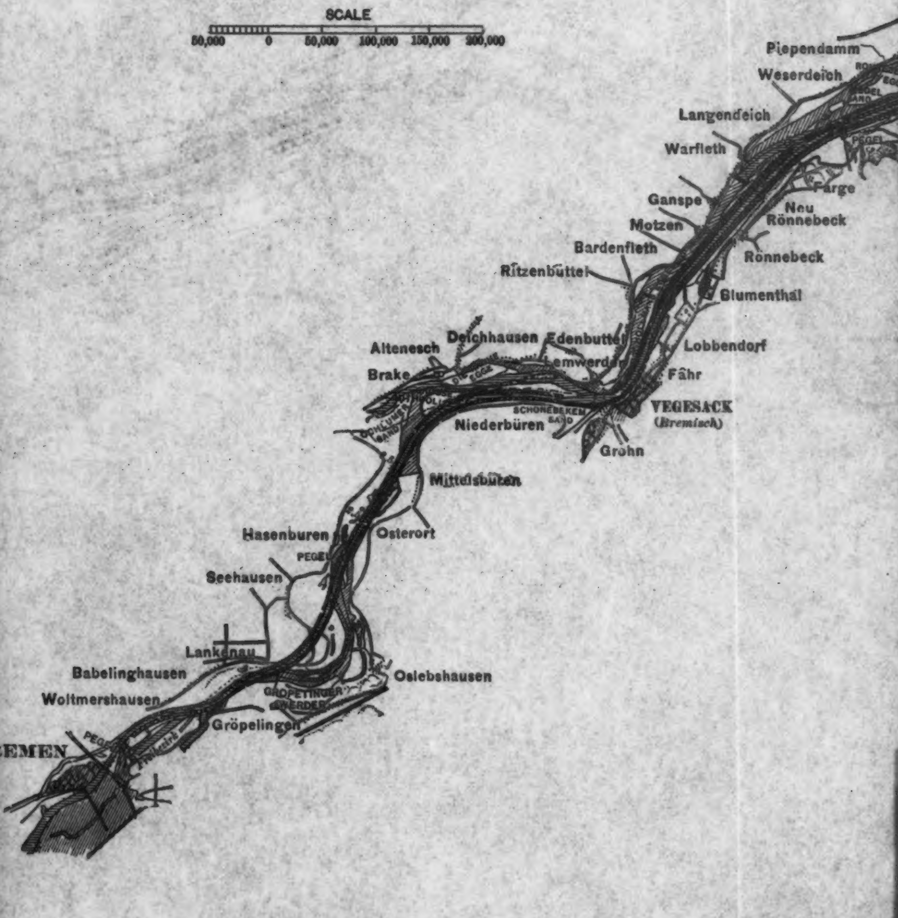
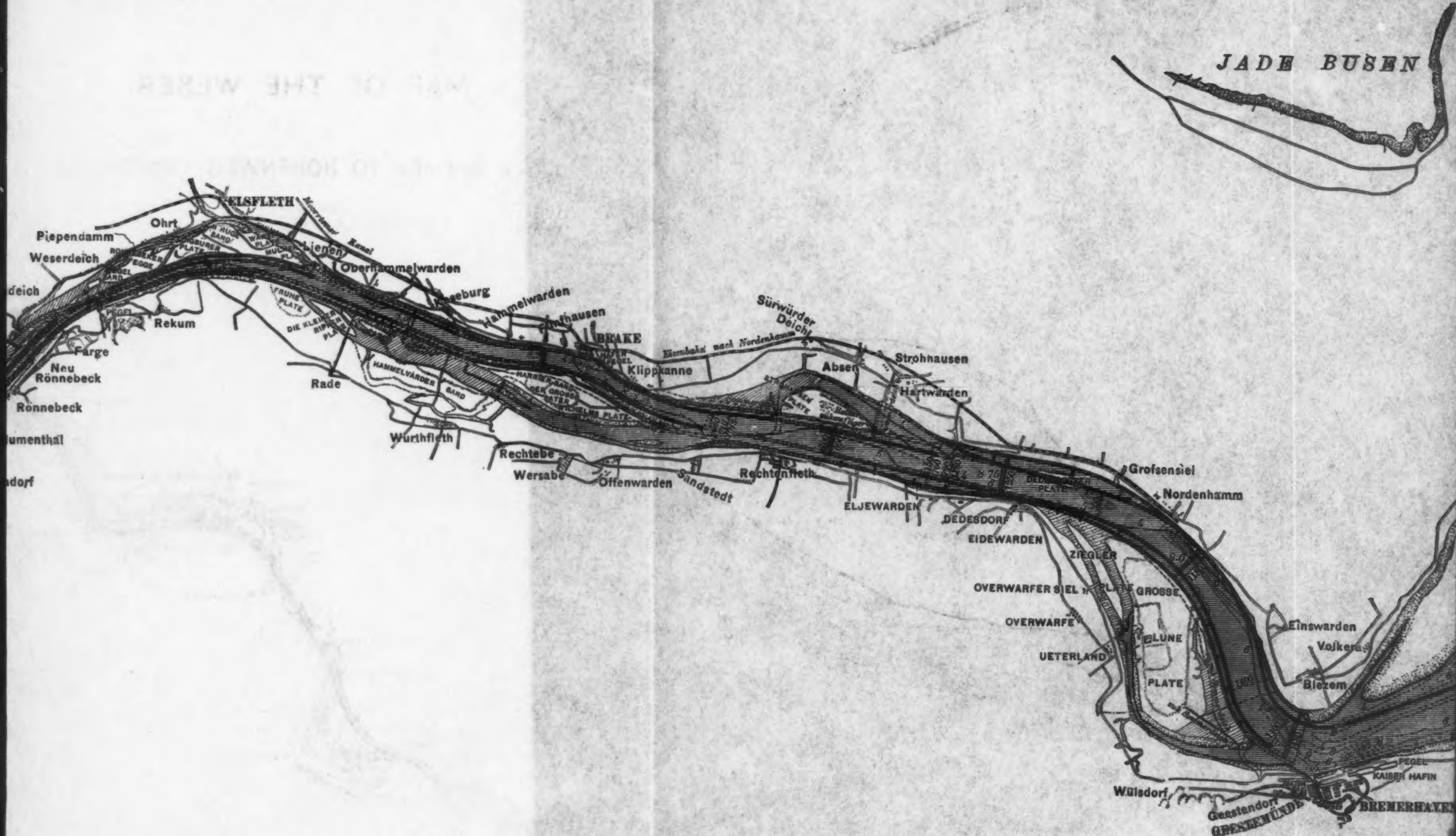
MAP OF THE WESER

FROM BREMEN TO HOHENWEG LIGHTHOUSE.





JADE BUSEN
ELSFLETH
Piependamm
Ohrt
Weserdeich
Lienen
Oberhammelwarden
Rekum
Farge
Neu Rönnebeck
Ronnebeck
Rade
Hammelwarden
BRAKE
Klippkanne
Sürwürder Deich
Absen
Strohhausen
Hartwarden
HAMMELWARDER SAND
Wurthfleth
Rechtebe
Wersabe
Offenwarden
Sandstedt
Rechtenfleth
ELJEWARDEN
DEDESDORF
EIDEWARDEN
Grofsensiel
Nordenhamm
ZIEGLER
OVERWARFER SIEL
GROSSE
OVERWARFE
LUNE
UETERLAND
PLATE
Einswarden
Blexem
PEGEL
KAISER HAFIN
Wulsdorf
Geestandorf
GEESTEMÜNDE

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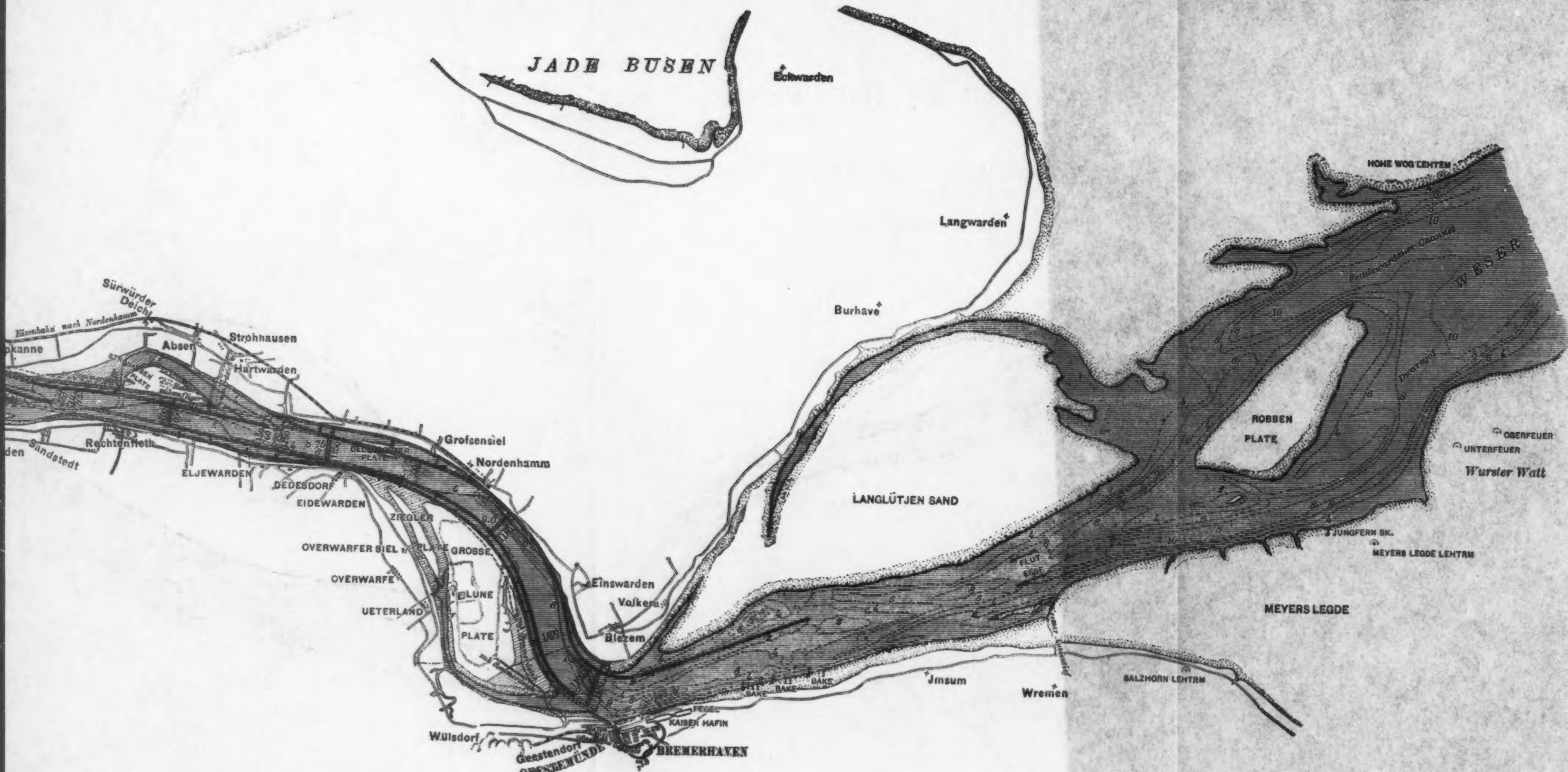
FRANZIUS ON IMPROVEMENT OF THE LOWER WESER.
PLATE II.



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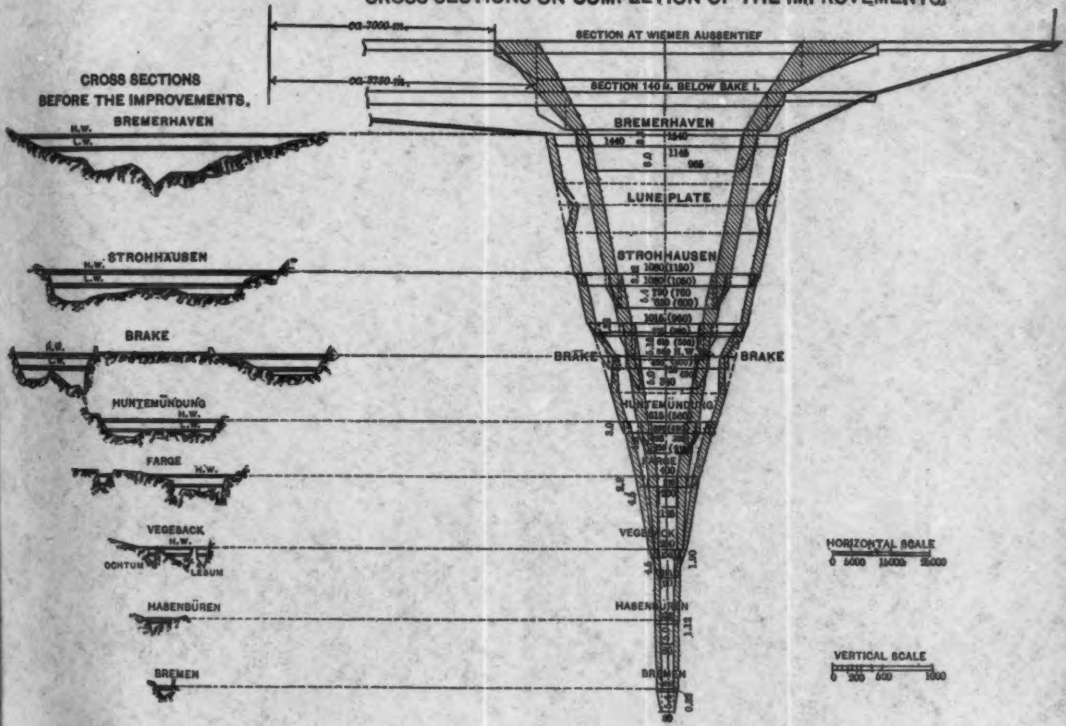
FRANZIUS ON IMPROVEMENT OF THE LOWER WESER.
PLATE III.

CROSS SECTIONS ON COMPLETION OF THE IMPROVEMENTS.



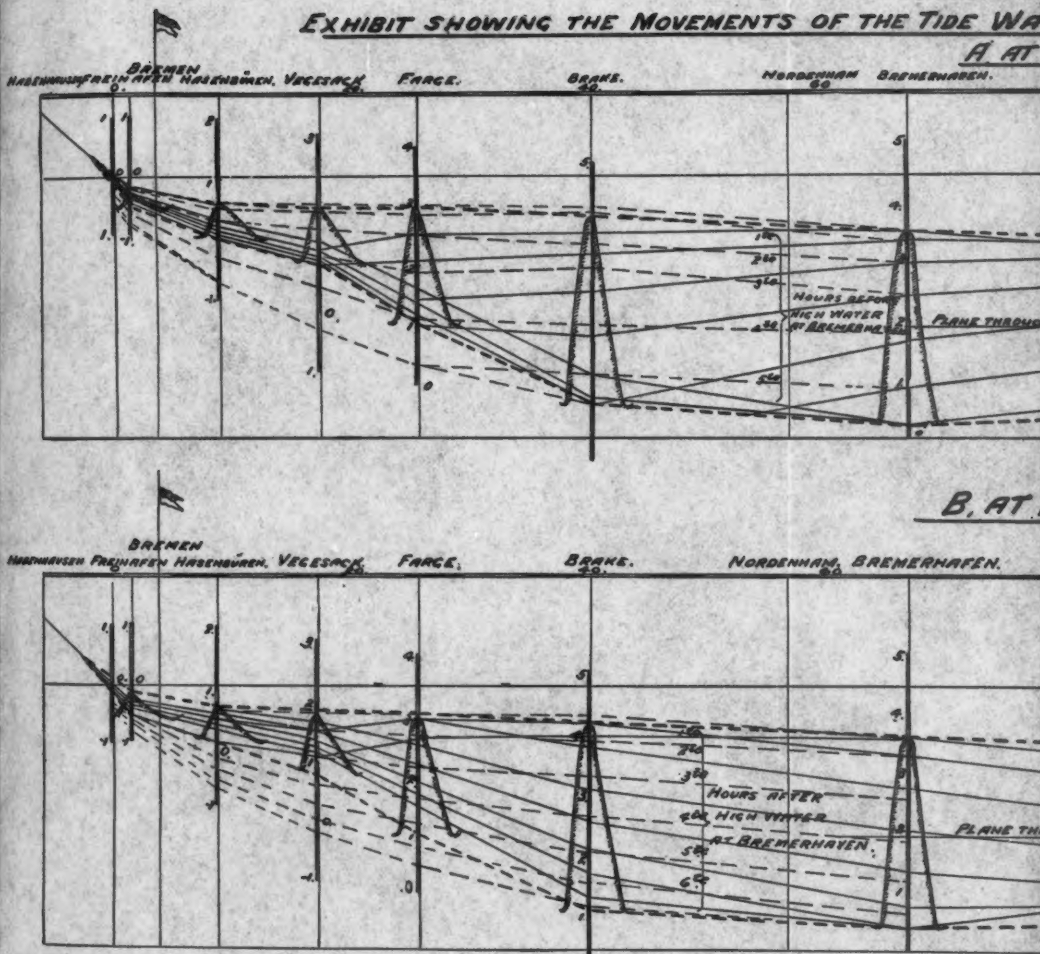
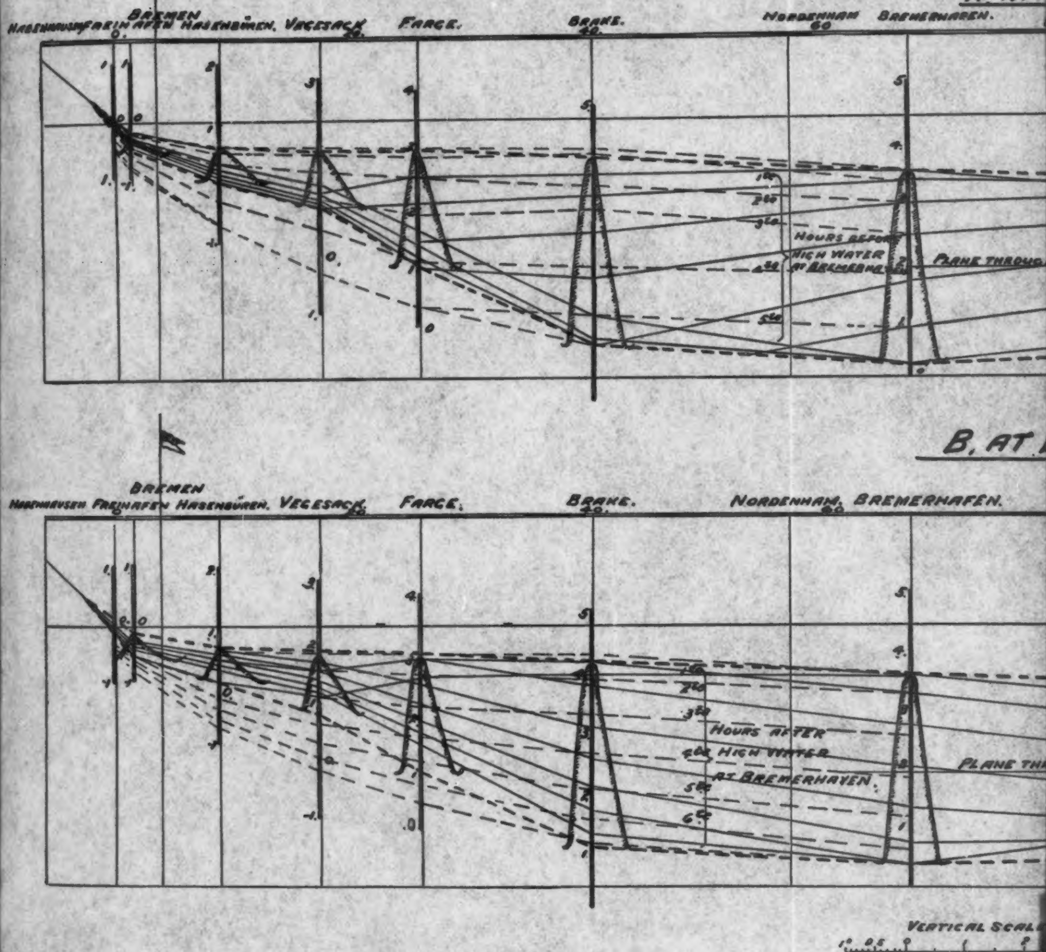


EXHIBIT SHOWING THE MOVEMENTS OF THE TIDE WA
A AT
BREMEN
HABENHAUSEN FREIHAFEN HASENBÜREN. VEGESACK. FARGE. BRAKE. NORDENHAM BREMERHAFEN.
HOURS BEFORE HIGH WATER AT BREMERHAVEN
PLANE THROUGH
B, AT
BREMEN
HABENHAUSEN FREIHAFEN HASENBÜREN. VEGESACK. FARGE. BRAKE. NORDENHAM, BREMERHAFEN.
HOURS AFTER HIGH WATER AT BREMERHAVEN.
PLANE THR
VERTICAL SCALE

EXHIBIT SHOWING THE MOVEMENTS OF THE TIDE WA

A AT



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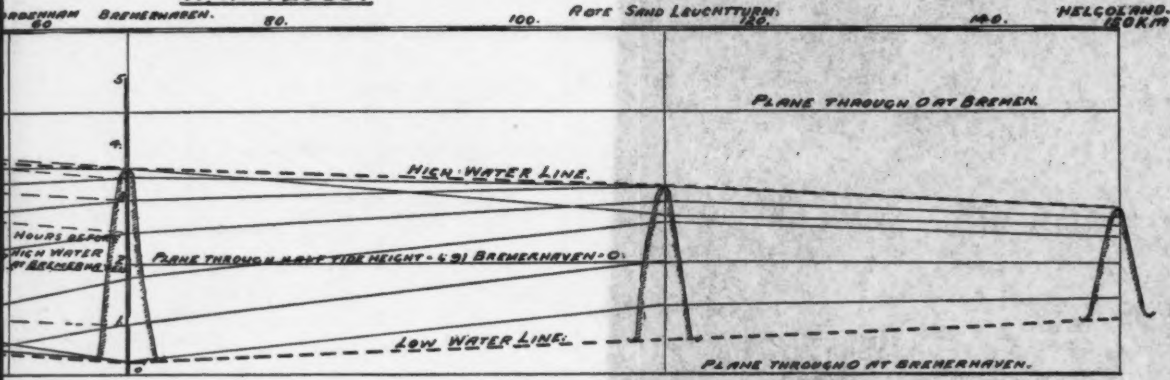
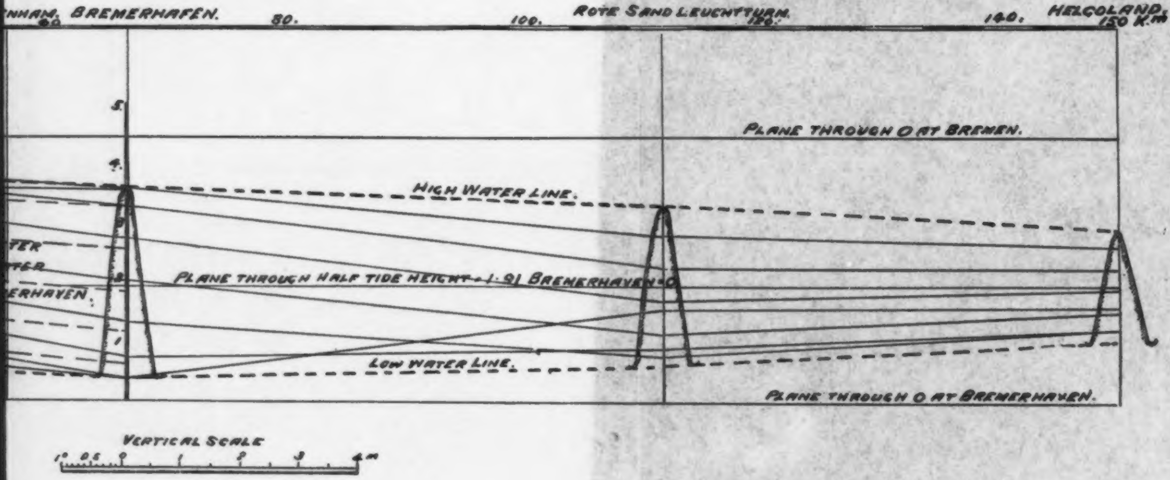
FRANZIUS ON IMPROVEMENT OF THE LOWER WESER.
PLATE IV.

S OF THE TIDE WAVE FROM HELGOLAND TO BREMEN.

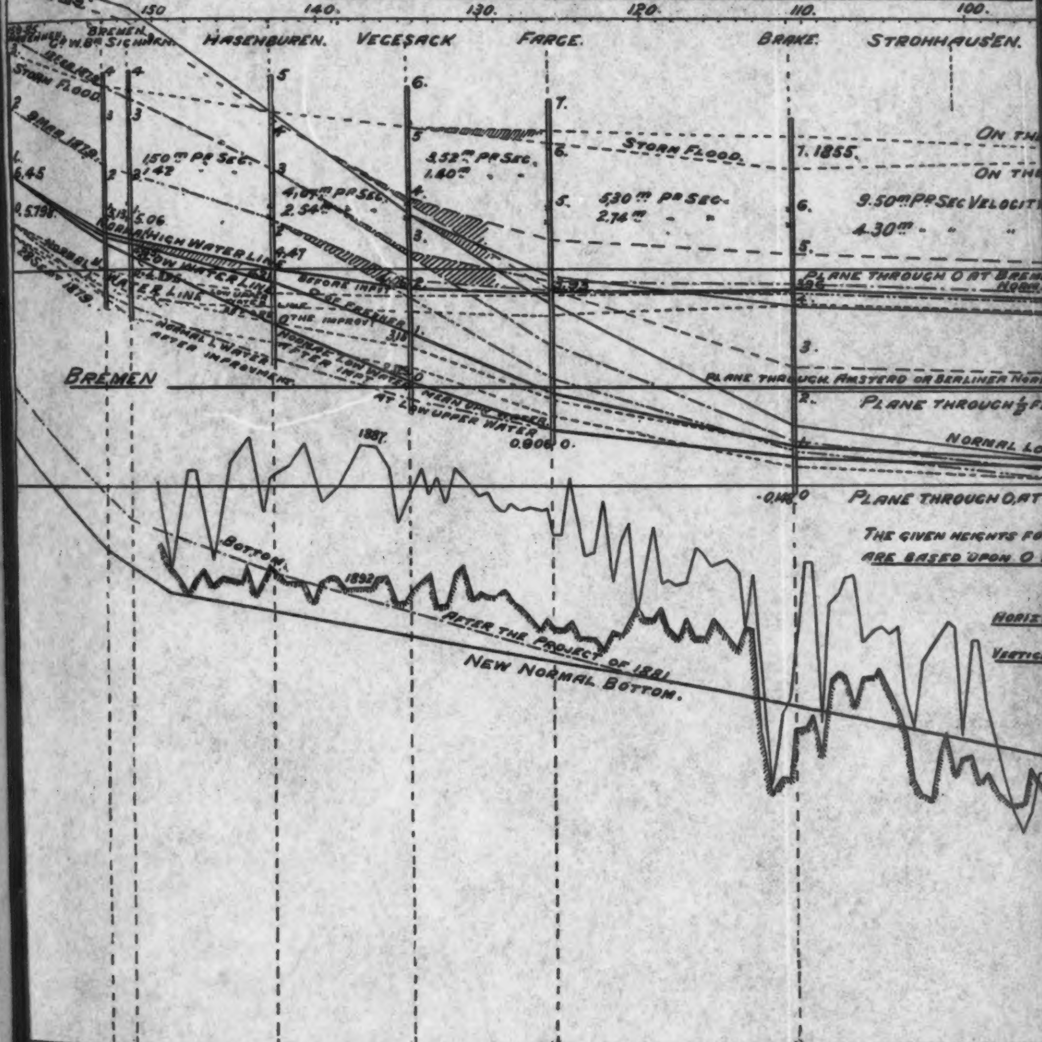
A. AT FLOOD.

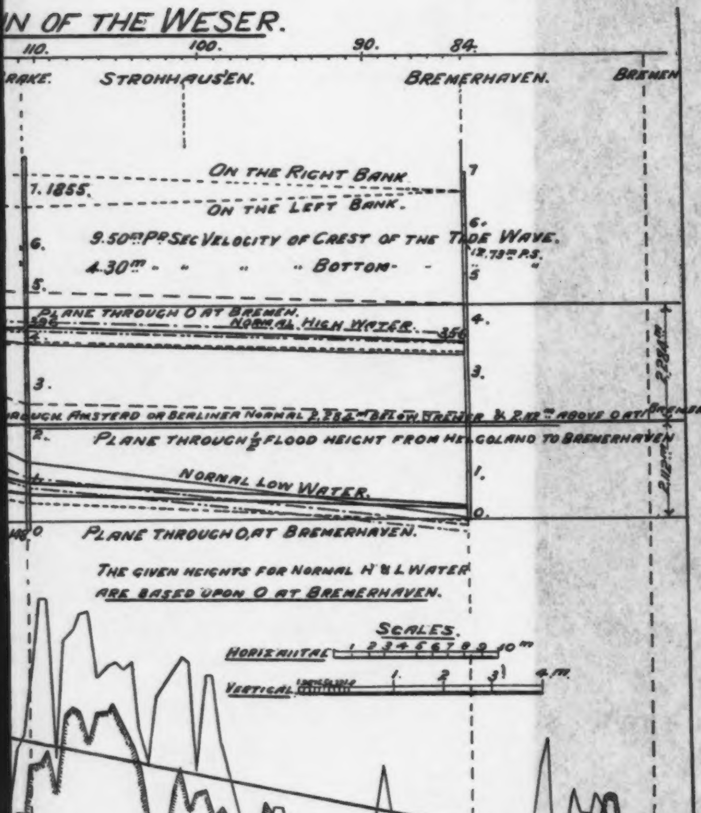


B, AT EBB.



PROFILE OF THE TIDAL BASIN OF THE WESER




N OF THE WESER.
110.
100.
90.
84.
RAKE.
STROHHAUSEN.
BREMERHAVEN.
BREMEN
ON THE RIGHT BANK
7. 1855.
ON THE LEFT BANK.
9.50m Pr Sec Velocity of Crest of the Tide Wave.
12.73m P.S.
4.30m " " " Bottom
Plane through 0 at Bremen.
Normal High Water.
2.284m
Plane through ½ flood height from Helgoland to Bremerhaven
Normal Low Water.
2.112m
Plane through 0 at Bremerhaven.
The given heights for Normal H & L Water are based upon 0 at Bremerhaven.
Scales.
Horizontal
10m
Vertical
4.m

ficient energy. Thus, by the removal of the shoals at Elsfleth, above the split near Strohausen, previously mentioned, which was done intentionally in the first years of the improvement, a lowering of the ebb-tide surface was actually obtained which extended over the whole upper section of the improvement.

It is obvious that in all such far-reaching changes, the existing conditions must receive more attention than the purely technical requirements, and that the preliminary estimate must take into account all possible claims for damages. For this purpose it is essential to measure exactly all existing facilities for drainage; to take accurate soundings of all water channels; to determine the amount of salt in the water with reference to its use by cattle; to make investigations of the character of the local vegetation, with the view of its possible alteration by the improvement, etc.

The following is the preliminary estimate of the cost of the project:

	Marks.
For land purchase and damages	495 600
For excavation, dredging and transportation (31 000 000 cu. m.)	23 641 212
For correction works	2 748 860
For secondary works	950 000
For administration, incidentals, etc	2 164 382
Total	30 000 000

Some of these amounts have since been materially changed, especially the fourth item, which has been considerably exceeded, while in the second item a considerable saving was made in consequence of the exceedingly low price paid for moving material.

Up to the end of 1892 there has been expended:

	Marks.
For excavation, dredging, transportation	10 920 313.07
For correction works	5 236 111.71
For secondary works	2 688 117.99
For administration, incidentals, etc	1 620 475.48
Total	20 465 018.25

AMERICAN SOCIETY OF CIVIL ENGINEERS.

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NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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(Vol. XXIX.—July, 1893.)

A BRIEF ACCOUNT OF THE BUILDING OF LEIXOES HARBOR.

By ALFONSO JOAQUIM NOGUEIRA SOARES, Inspecting Engr. in Charge.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Leixoes Harbor, situated about 5 km. to the north of the mouth of the River Douro, is formed by two break-waters, the northern one extending 1 579.37 m. in length, and the southern, 1 145.25 m. The outlines in plan from the shore are concave to seaward, as far as low-water level, in order to insure the best protection to the stoneyards and service roads, as well as to enlarge the area. Beyond this their advancement into the sea is in right and parallel lines, whose approximate distance is 1 100 m., and whose bearing is S. 73° 30′ W. They

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

then approach each other, curving towards the inside of the harbor, with 300 m. and 200 m. radius, respectively, for the north and south moles, and afterwards continue straight to their outer ends ; leaving an opening 220 m. wide for the entrance, but so that the break-water from the north extends about 150 m. further into the sea than the one from the south.

The north break-water, which in part rests upon several rocks that are visible at low water, and even at high tide, is the most important, as it completely shelters the harbor from the northwest swell of the sea, the most violent here.

The area of this harbor, measured at lowest water level (hydrographical zero), is about 95 hectares (234.75 acres). At high tide it is considerably larger, as it then includes the tide-basin of the River Lessa. The depths of 8 m. and more, indicated by the soundings figured in meters on the plan and represented by contour lines, also figured in meters as well as in English feet, are all referred to the hydrographical zero. The area within these contours covers an area of 40 hectares (98.84 acres), and the harbor admits the largest merchant ships, whose access is, in general, easy.

The construction of the break-waters in deep water was by what is called the mixed system. The lower structure or submarine basement is a mound of loose rubble stone, assorted in three different average sizes. The stones of the first or least size do not weigh more than 2 000 kg. each ; those of the second size range from this weight to 8 000 kg., and those of the third are still heavier. The seaward slope or foreshore is defended by artificial blocks, 20 cu. m. each in bulk and about 45 000 kg. in weight, made with rubble stone bedded in mortar and with concrete. The upper structure or sheltering wall is built with hewn stone faces and rubble stone backing, all of which is laid in mortar, these materials being joined in artificial blocks of about 20 cu. m. in the part most exposed to the sea.

The loose stone masses of assorted rubble, as well as the artificial blocks, are so placed that the most bulky materials occupy the positions most exposed to the destructive action of the waves. Accordingly, on the base for the upper structure, at the level of zero, the second-size rubble, that goes down 5 m. below this datum, is covered, in the first place, by third-size rubble, and after that, by the artificial blocks. These rise against the outward face of the upper

structure about 5 m. above datum, and descend below datum to the depth of 7 m., where they rest upon the third-size rubble mass, because at greater depth, the agitation of the sea not being so effective, great mass is not required for the defense of the inner less weighty materials. The breadth or thickness of the mound at datum is 38.24 m., the artificial blocks occupying the width of 15.8 m. between the seaward slope and the sheltering wall.

The upper structure is 5.4 m. thick at datum level, has its outward face battered 1 horizontal to 10 vertical, and has a height of 9.8 m. Its thickness at the top, barring the jut of the cordon, is 4.5 m., which is divided into 3 m. for the width of the walk and 1.5 m. for the base of the parapet, whose height, 1.4 m., makes the total elevation of the upper structure 11.2 m. above extreme low water, or 7.4 m. above the highest tide.

The upper structure, in addition to being protected on the sea side by artificial blocks to the height of 5 m. above datum, is on the harbor side supported by first-size rubble and by the pavement laid in mortar, which, at 6 m. above datum, forms the plane of the quay, 10 m. wide ; so that the thickness of the break-waters is 14.8 m. at the level of this plane. Below datum level the thickness or breadth of the mounds increases with the depth. The slope of the rubble on the harbor side is 1.33 m. horizontal to 1 m. vertical, and that of the artificial blocks on the sea side is 1 to 1 to the depth of 7 m., where the covering of this class terminates, being followed by that of third-size rubble, which still increases the breadth, as may be seen on the section.

The construction of the heads of the break-waters followed what is called the upright wall system. The foundations were formed with concrete in bags, so as to give regularity to the rock bottom, after the sand and movable detritus were taken away by means of dredges and the work of divers. The foundation of the north head is buried in the general bed of sand. The greatest thickness of the concrete in bags there is 2.7 m., and its upper surface, that on an average is at the same level as the upper surface of the sandbed, is 14.85 m. below datum. For the foundation of the south head advantage was taken of a large submarine rock which rises about 5 m. above the bottom, so that, to establish uniformity of surface in the same way by means of concrete in bags became much easier, a plane upper surface being left,

upon which the upright wall rests, at the depth of 9.9 m. below the datum level.

The height of the upright structures from their bases to this datum is, therefore, 14.85 m. and 9.9 m., respectively, at the north and south heads. In both of them the thickness of the rectangular part is 15.4 m., and the thickness or diameter of the circular part, 20 m. Below datum these structures were executed as follows: the circular part at the north head and the rectangular part at both of them were built with artificial blocks of various dimensions, but in general ranging in bulk from 16.5 to 20 cu. m., made of rubble stone bedded in mortar, which were placed in horizontal courses or layers, without mortar in the joints and beds. The circular part of the south head was built within an iron caisson that was lined with rubble stone bedded in mortar and filled in with concrete. After a coating of these materials had been laid dry-shod on the bottom and against the sides, the caisson was sunk in place, and was afterwards kept drained with a powerful centrifugal pump, in order to allow of the interior constructions being continued dry-shod, so as to form a compact body.

From datum to the quay level, 6 m. above, the heads were constructed with artificial blocks, hewn stone and stone rubble, all with mortar in the beds and joints, so that the masses are perfectly compact. Above the quay-plane, the upper structures or sheltering walls agree with those on the mounds and are constructed like them.

The principal materials of the country, stone for all sorts of masonry and sand for mortar, were of excellent quality and were found in very favorable working conditions. The cement came from the important establishment at Boulogne-sur-Mer with the mark "Demarle Lonquety & Cie.," in accordance with an agreement between the contractors of the works of the harbor and the manufacturers.

The mortar used in making the artificial blocks for the protection of the loose rubble masses and for the construction of the upright walls was made with this cement and sand, in the proportion of 556 kg. of the former to 1 cu. m. of the latter. That applied to the hewn stone outward coating of the sheltering wall above the quay-plane was also made with cement and sand, in the proportion of 600 kg. of cement to 1 cu. m. of sand, or of 1 of cement to 2 of sand, and that used in the backings was mixed with water-lime of the country (Cabo Mondego),

puzzolana, also Portuguese (Ilha de S. Miguel) and sand, in the proportions of 632 kg. of lime, 1 cu. m. of puzzolana, and 3 cu. m. of sand.

The entire work was taken at a lump sum (*a forfait*) by Dauderni and Duparchy, according to the plan and minute specification, in which every detail was determined. These contractors were, after Dauderni's decease, succeeded by Duparchy and Bartissol. The contract with the Government was closed on the 16th of February, 1884, in pursuance of public competition announced for January 23d of the same year, when the only proposal offered was that of these contractors, who discounted 11 000 mille réis on the assigned limit of cost, 4 500 000 mille réis, which was accepted.

According to the stipulated conditions, the contractors were to begin the work within six months following the date of the contract and finish it within the term of eight years after the same date.

The former condition was observed. The latter was not exactly fulfilled, on account of several accidents, in particular those that occurred on the immersion of the iron caissons for the circular parts of the heads of the break-waters. This expedient, previously adopted at Columbo, was proposed by the contractors to hasten the works and save the corresponding outlay, but did not turn out to their advantage, and experience proved that they would have served their interests better in executing without any alteration what was provided for in the plan and specification of the contract; as they had to do after all at the head of the north breakwater. Notwithstanding, the difference was only of a few months, and the works executed after the term expired were not very important; so that the harbor, as to the advantage taken of it, might indeed be considered ready within this term.

At all events, it seems that, as yet, no works for sea harbors of the same nature and importance have been perfected in so short a period, in a sea so much exposed to the winds of the northwest and southwest on such an extensive area, and with a section of construction so solid and complete for internal shelter.

The placing in the sea of the assorted loose rubble and the protecting artificial blocks, as well as of those with which the heads were built and also the walls on the mounds above the datum level to the quay-plane, 6 m. high, disposed in three layers that occupy all the

width of this upper structure, was mainly effected by means of the large powerful cranes, "Titans," constructed at Fives-Lille Iron Works, which did excellent service. All the stone placed with these "Titans" was brought from the quarries on the coast, or from those at San Gens, by railroads laid out for the purpose, the main supply being from the latter. A comparatively small portion of rubble from the quarries on the banks of the River Douro was put in place in the sea by means of steam hopper-barges.

The progress of the work was in general very satisfactory, excepting the losses that resulted from accidents attending the immersion of one of the iron caissons for the heads of the break-waters, and from the abandoning of another very forward in construction. In reference to the importance of the total affair, these cannot be considered very remarkable, and the contractors were on the whole very fortunate, as the damages they suffered came to much less than what, with good reasons derived from the experience of similar works, was apprehended and provided for in the computation of the amount and prices of the estimate. However, to be just, it should be acknowledged, not only that several circumstances were favorable, including the weather and the state of the sea, but also that the contractors endeavored to secure a successful result and maintained an orderly, active and economical management.

Experience, during the building of the harbor, has already confirmed, and it is thought it will continue to confirm in its use and maintenance, that the system of construction designed in the plan and specification of the contract, and which the contractors bound themselves to carry out, was appropriate to local conditions; thus contradicting the ill omens pronounced by respectable engineers of several countries before and after the works were begun.

The principal quantities of work, that according to the plans of the work and the conditions of the contract were valued and paid to the contractors are: 608 836 cu. m. of assorted loose rubble in the sea; 125 480 cu. m. of artificial blocks for the defense of these rubble masses; 3 252 cu. m. of concrete in bags in the foundations of the heads of the break-waters, 11 068 cu. m. of artificial blocks set without mortar in the heads; 9 694 cu.m. of concrete and of rubble masonry set in mortar within the caisson of the south break-water head and at the upper parts of both heads from datum to the quay-

plane level; 131 274 cu. m. of hewn and rubble stone masonry and artificial blocks laid in mortar in the sheltering walls on the mounds and at their heads, and 18 400 cu. m. of rubble masonry with mortar in the pavement of the quays.

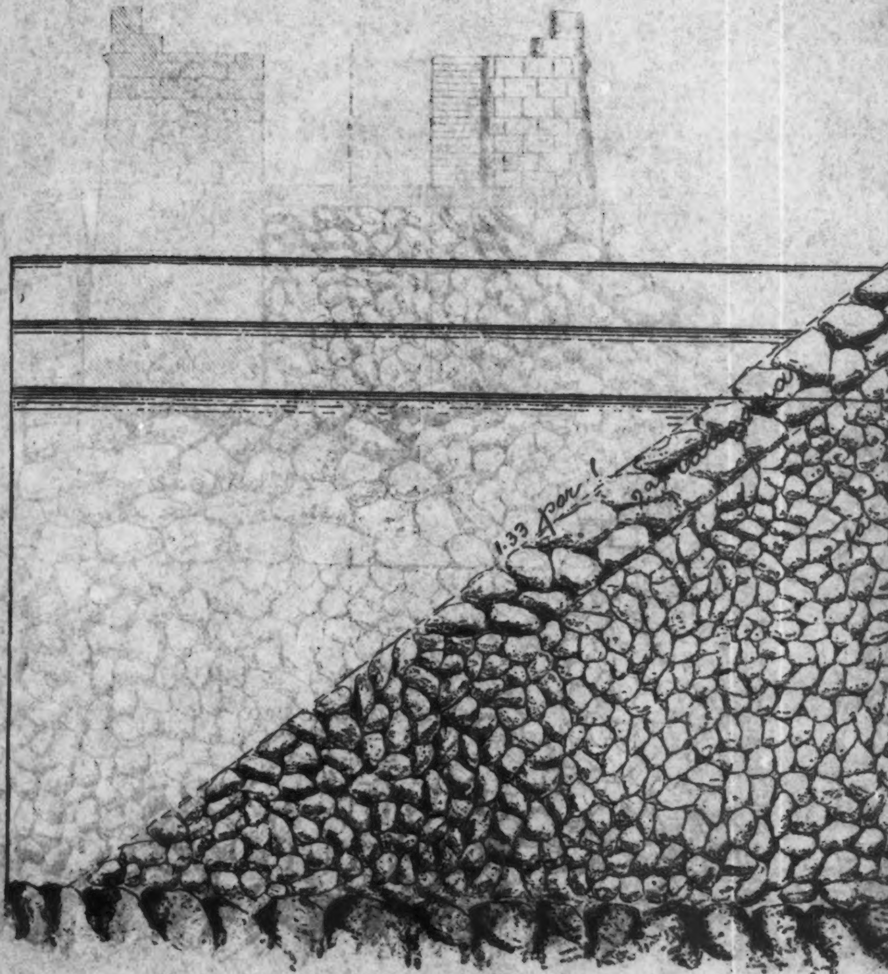
There were used on the mounds and quay walls of the little port of service that was constructed against the north break-water 16 840 cu. m. of artificial blocks and hewn and rubble stone masonry laid in mortar. Various ancillary works of the stoneyards, service roads, warehouses, etc., required 11 320 cu. m. of hewn and rubble stone set in mortar; 7 689 cu. m. of dry rubble masonry; 52 940 cu. m. of earthwork; 700 tons of iron, and large quantities of different sorts of timber. The lengths of all the service railroads amounted to a total of 30 km. during the greatest development of the works.

Besides two large cranes (Titans) used for building the break-waters, the contractors had two steam cranes, one of 25 000 kg. power and the other of 18 000 kg., on the construction of the small internal port; two steam screw-jack wains (*chariots à verin*) of 60 000 kg. in the stoneyards to lift and convey the artificial blocks; as well as 25 cranes ranging from 1 500 kg. to 18 000 kg. power at the quarries and in the stoneyards. There were also seven locomotives, three for the service of the quarries and four for that in the stone-yards, as well as different fixed and movable engines in the stone-yards and workshops.

The principal floating plant employed by the contractors consisted of two large steam hopper-barges, to place loose assorted rubble in the sea, and artificial blocks at the heads of the break-waters, their service in this work being of little use; a small steam tug and different boats for dredging at the foundations of the heads and for the conveyance of materials.

This harbor will soon have two secondary lighthouses built upon the heads of the break-waters and in the general plan of coast lighting, the construction of one of first class is also intended for its vicinity. It is also to be completed with internal works, in order to adapt it better to commercial operations, for which purpose a law has already been promulgated, but not yet put into execution.

The use that navigation has made of the harbor is already important, for, besides many coasting and fishing vessels that, in great danger in the open sea, took refuge in it, large ships have come into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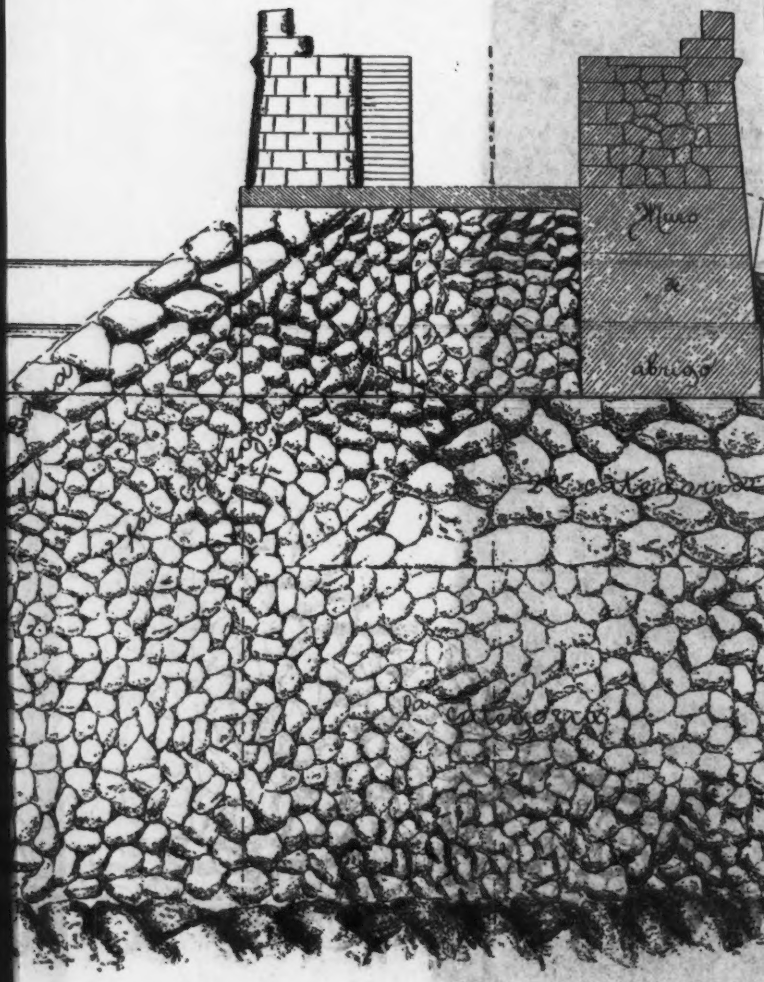
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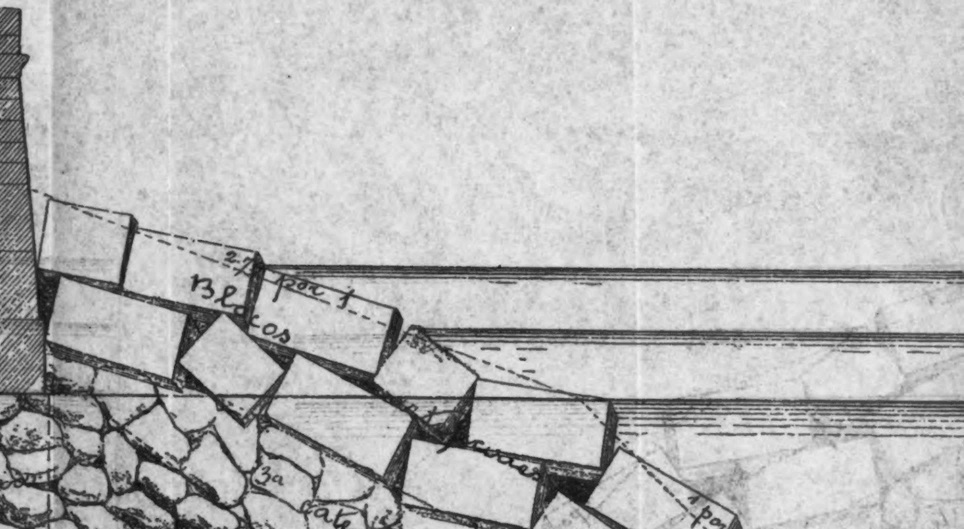
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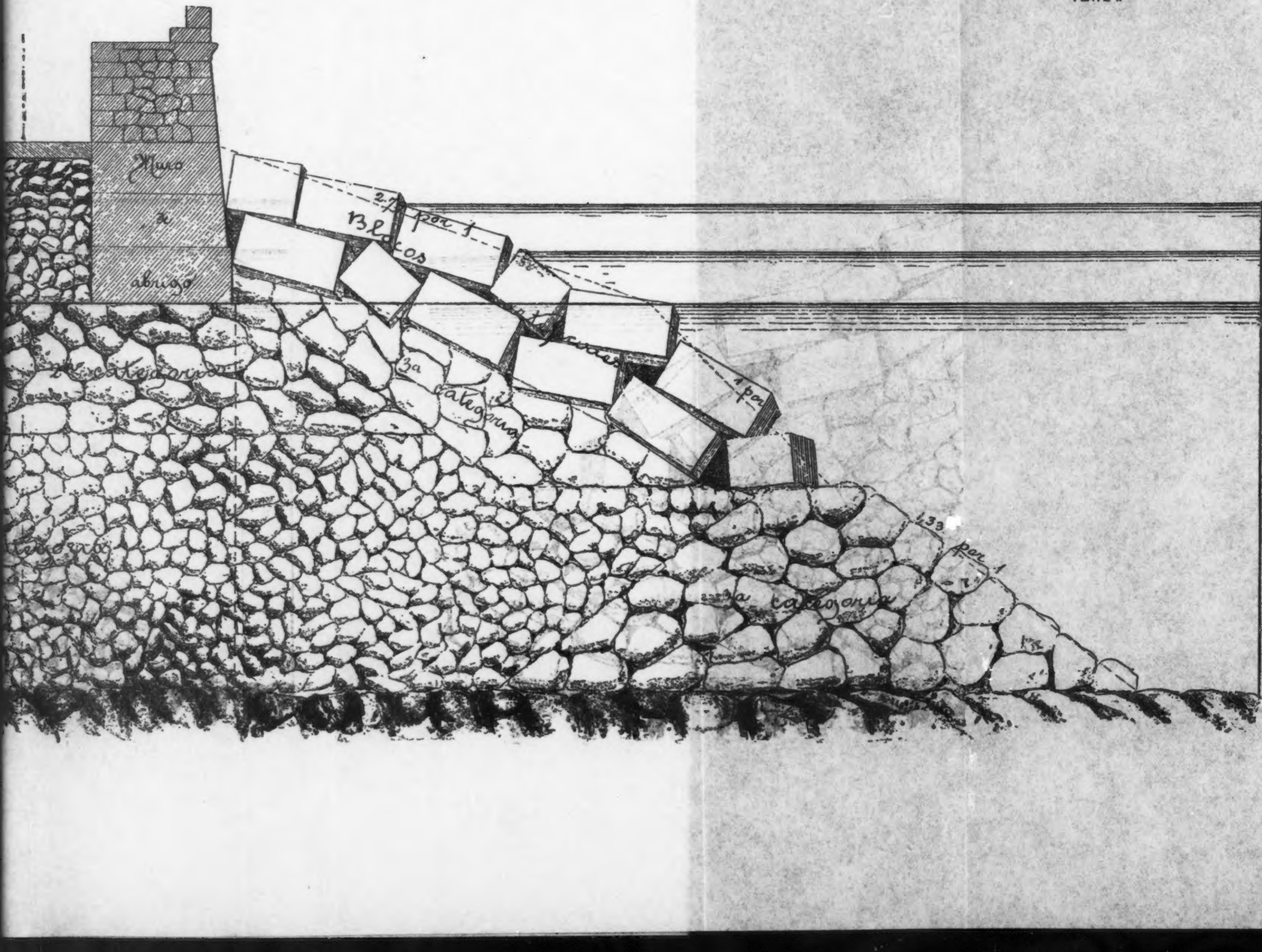
SOARES ON BUILDING OF LEIXOES HARBOR.
PLATE I.



it for shelter or for commercial operations, as well as steam-packets bound to it expressly.

This harbor is liable to deposits of sand and silt from maritime and fluvial sources, as in general all artificial and even natural harbors are; but the experience gained, up to the present, suggests that the expense of maintenance in dredging will be very moderate.

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THE LIMITS ATTAINABLE IN IMPROVING THE NAVIGABILITY OF RIVERS BY MEANS OF REGULATION.

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Translated from the German by KENNETH ALLEN, M. Am. Soc. C. E.

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When water reaches an inclined surface the effect of gravitation is to set it in motion. Thus, the water acquires a certain energy, that is, the ability to perform mechanical work.

Should the water—which, for the present, is supposed to have a continuous and uniform flow—meet with no obstruction on its way down the valley, then in a given time it will perform as much work as has been expended during that time in giving it motion. But if

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obstructions are to be overcome on the way, a portion of this energy proportional to the resistance will be consumed, therefore measuring its amount up to that point of time. Because gravity acts continually, therefore, in the first case, in consequence of the increase in velocity with the fall, and the fact that a body with mass m moving with a velocity v possesses a capacity for work equal to $\frac{mv^2}{2}$, the energy descending would constantly increase with the increasing difference of level h from the origin of the movement, in conformity with the increase of v and according to the formula $v = \sqrt{2gh}$. In the second case a certain amount of the increased velocity will be absorbed in a given distance by the expenditure of that amount of energy required to overcome the obstructions occurring along this distance.

Our natural water-courses are in this category. In the completion of the circulation, constantly being renewed under the influence of the sun's heat upon the sloping surface of the earth, these flow toward the sea; and, since their creation, together with atmospheric influences, continually act on its ever-changing surface. The acceleration imparted to the water will be partly consumed in overcoming resistance to motion caused by adhesion and friction between the bed of the stream and the water. The adhesion and friction produce on their part internal motions through the cohesion of the water, and thus a further part of the acceleration is destroyed. Should this be just consumed over a certain distance, the water will flow for this distance with a constant velocity; if it is but partially consumed, the water at the end of the distance will have attained an increased velocity; if the acceleration is insufficient to overcome the resistance to motion, then the velocity will have become less at the end of the distance. In the last two cases the water has a varying velocity. In the first case the energy has remained constant; in the second case it is increased; in the third case it is decreased. We can also say with Lechalas (*Hydraulique Fluviale*, Paris, 1884), that in the first case the total work performed by all forces in a unit of time is *nil.* While the negative work is expended in overcoming the resistance caused by adhesion, friction and cohesion, the positive work may be taken as approximately equivalent to the product of the weight of the flowing water by the actual fall in the given distance. This is only approximate, because, as a matter of fact, the stream carries silt,

which increases in amount as the power of erosion exceeds the resistance of the bed. Sediment is the product both of the eroding action of the water and of the disintegration caused by atmospheric influences.

As the stream, which at a certain instant possesses a certain energy, attacks the bed, which is variable in its composition as well as in density of stratification, it forms its ground plan in compliance to the resistance to motion encountered, by avoiding them with a bend, *i. e.*, by changing its direction. In this manner a loss of energy occurs. The stream will, therefore, leave the bend with a less velocity than it had on entering it. In the bend itself a part of its energy must be absorbed, and that occurs here by internal motions, as is made apparent by eddies. These internal motions of the water occur as a result of the cohesion between the molecules moving with different velocities. This difference in velocity is observed to be more marked, and hence the internal movements are of greater magnitude, the nearer the molecules approach the bed of the stream.

Now, the intensity with which the molecules are driven against the stream-bed depends upon the shape of the channel, both horizontally and vertically. In a bend, the water will be driven against the concave bank by its centrifugal force, and in this way eddies with vertical axes are formed. As the water breaks against the shore it is raised, and thereby, under a correspondingly increased pressure, receives an impetus to flow back normally into the bed of the stream. These filaments of water impinge on those flowing obliquely down stream, causing the formation of other eddies with horizontal and inclined axes, which continue downward to the stream-bed and attack it in the neighborhood of the concave shore, as well as the latter itself. A change of form in the cross-section takes place by this one-sided deepening and widening. There are, therefore, two factors present which deduct a portion of the stream's energy on entering a bend—change of direction and change of form. In addition to this there is a third. The materials torn from the banks will, in proportion to their weight—*i. e.*, in case of equal specific gravity in proportion to their volume—either be drawn into the eddies by the whirling mass of water and carried off in suspension by the current, or rolled forward on the bed of the stream. This, also, is work performed which is only possible by a loss of energy.

The diminution of energy caused by bends is made evident in the first place below the bend, and, moreover, on the concave shore, by the deposition of the eroded material, the convex shore joining the concave shore down the stream. Therewith, however, the water is crowded over to the opposite shore and receives another change of direction. But while the remaining energy is entirely consumed by overcoming resistance, there will be formed no other important internal motions in crossing from one shore to the other, so that eddies working to deepen the channel will be wanting ; in other words, the bed will show here an elevation, as in part the products of the erosion in the bend above come to rest. This increased elevation acts as a bar, raises the water surface above it, and endues it with new energy, the surplus of which, when reaching the opposite shore, will be consumed by the formation of bends and pools, as in the former concave shore. We have here the formation of a serpentine channel.

Up to this point we have assumed a uniform quantity of water flowing over a bed of originally constant inclination to the horizon. We have seen that this inclination has a certain legitimate dependence upon the slope of the bed ; that, as soon as bends occur, the slope, which is at first continuous, is interrupted by pools which are formed along the concave shore.

In accordance with these principles the surface-slope is determined. The latter is the expression for the transporting power of the water. The water enters the bend with a surplus of energy and leaves it with a deficiency of the same. Above the bend, therefore, the surface-slope is greatest; in the bend it is used up in the formation of eddies. The lost fall is restored, however, by the raising of the surface of the water caused by the rising bed or dam below the bend.

Now, bearing in mind the assumption of a constant volume, and, also, that no sediment is brought into the stream from outside, when is the attainment of stability in the conformation of the channel formed by the stream itself to be expected? Evidently this is, in general, when the energy at the entrance to the concave side has become equivalent to the resistance of the bed and shore against erosion. Assuming that the stream is left to itself, equilibrium between the scouring action of the water and the resistance of the bed is only attainable by the independent diminution of the former. With a uniform discharge, such a result is only possible by a lessening of the

velocity. This depends upon the assumed uniform friction on the perimeter, and upon the size and form of the cross-section, as well as upon the fall.

Under the assumption that the shore and bed possess the same firmness, the one-sided deepening of the concave bank and its simultaneous caving in, will change its position continually. Hence, the eddies causing the deepening will not attack the same part of the bed long at a time, so that the sharpening of the curve limits the depth of scour. The length of the stream increases at the same time with an increase in curvature, that is, the relative fall of the water-surface, and hence its transporting power decreases. Under these assumptions, equilibrium must, within a certain time, be established through this play of forces.

In order to approach more nearly the truth, let us now assume that the volume of water which, until now, we have considered constant, by which perfect equilibrium may have been attained, receives an increase. The equilibrium instantly ceases. The contour of the bed has adapted itself to the action of a smaller volume of water. The action on the bed and shore must therefore increase with rising water and the additional energy. It is obvious that the places first disturbed will be those which came to rest the last, *i. e.*, the bed and shore on the concave side, assuming as before that there exists no artificial protection, and that they are therefore open to all action of the water.

When the water rises still further, the ridges of the bed separating the pools will come into motion. The bed is about to change its form, and, moreover, for such time and in such manner that it at last adapts itself to the increased scouring action of the high water. If, therefore, the high water lasts long enough, the result here must also be a condition of stability in the bed of the stream.

If the water falls again, energy is lost. If we suppose a state of equilibrium reached, and if the high water finally finds a bed which can withstand its attacks, the diminished current will be yet more powerless to alter the form and size of the bed. By the high water, too large a bed has been prepared for the lower stage. Consequently, an excess of energy is developed which is afterwards absorbed by eddies; then, in consequence and in place of this by the erosion of the bed and shore, the low water scours for itself a serpentine channel in the high-water

conduit, until such time as the excess of energy caused by the diminished fall shall have been entirely consumed.

Now, it is erroneous to suppose that in Nature the high water will last until the bed has become stable under its action. On the contrary, during the state of high water, just because it does not last long enough, the whole bed is in motion, the deposits assuming different velocities forward depending on their size, form and weight. The heaviest slide or roll along the bottom ; the lighter ones are carried in suspension down the valley.

With falling water the energy decreases. Then the scouring of the bed ceases, as a greater force is necessary to tear the material loose from its resting place than is required to transport the material already loosened. The stream now carries sediment only. Gradually, with the falling water, it loses this power also, and the sediment comes to rest. The place of deposit is usually independent of the shape of the stream. At a certain instant, when the water has fallen so far that it has not the required energy, the sediment falls, or remains where it happens to be at the time.

Here the fact is to be noted, that a separation of the sediment according to its weight takes place in such a way that, where there is the strongest current, the heaviest material is set in motion; while in places where there is less current, especially where free from eddies, only the lighter material is set in motion. With falling water, therefore, it is not always the heaviest sediment that is deposited, but, as, for example, where both convex and concave banks occur, both light and heavy matter at the same time. But, while all movement of sediment ceases very soon on the convex side, there occurs on the concave side, on account of internal motions, a transport of such lighter material as has already come to rest on the convex side. Only when this material is carried by the eddies from the concave to the neighboring convex side does sedimentation take place. The new condition of repose in the stream-bed occurs only with the cessation of all motion in the material on the concave side. Then the stream, which at high water has usually a more direct course, and therefore a greater and correspondingly less changeable fall, has been transformed into a low-water stream with sharper curves, and hence more variable fall, and generally (on account of the increased length of the stream) of diminished fall.

If a tributary enters the stream at any point, we have to deal with two reaches of the river of different nature, divided by the point of confluence. The lower reach receives an addition, both in the volume of water and also of eroded mineral matter. The energy at the confluence must necessarily be changed, and will be greater or less, according as the tributary carries respectively more water or more mineral matter. In the first case, the surplus energy is dissipated by a scouring out of the bed and lowering of the surface, and a reduction of the slope below the point of intersection occurs which is connected with the slope above by a line of greater slope. In the second case, the preponderance of mineral matter brought from the tributary produces an increased resistance which the existing energy is insufficient to overcome. This can only be effected by a rise of the water above, by which the greater fall necessary to produce the moving power is brought about. The line of slope shows a rise at the mouth of the tributary.

There is less necessity for fall with an increasing volume of water, assuming a similar construction of the bed. In reality the volume is increased only spasmodically in consequence of additions from tributaries, but it is constantly augmented by the ground water. This plays an important part, at least so long as the ground water entering at the sides is under a higher pressure than that in the channel. The pressure of the latter is measured by a column of water with a height equal to the distance from the bed of the stream to the surface, and hence it decreases with a fall of the water. In general, therefore, this subterranean feeding will take place chiefly during low water ; while, on the contrary, during a high stage, when the stream is under greater pressure, it is forced into the subsoil at the bottom and sides. This phenomenon is in so far important, as by the coming forth of the ground water during a lower stage the stability of the bed is lessened, but is increased at high water. In the first case, the bed will become loosened and its mobility increased ; in the last case it is lessened. By the motion of the molecules from top to bottom, or from bottom to top, fresh disturbances of the flow—new energy-consuming eddies—are produced, a factor entirely passed over in previous "rational theories" of the motion of water in natural water-courses !

The foregoing explanation demonstrates without further argument that if the bed of a stream for the entire distance were composed of

similar material, the slope of the surface would decrease at such a stage as would render possible the feeding of the stream by ground water, *i. e.*, generally, during low water. Under these conditions, however, a continual alternation of greater and lesser slope exists in reality, by reason of this constantly decreasing fall, corresponding to the pools and bars; greater and lesser depths following and limiting one another caused by the bends. Evidently, this change will be more marked the lower the water, and, *vice versa*, it will be less so the higher the water rises. But even if we suppose that the stream had to overcome similar material for its entire length, a decrease of slope after any continuous bend would be quite impossible with the discharge of tributaries, while, as we have seen, every such mouth must necessarily cause a change of slope. This impossibility is the more marked as our water-courses flow in beds whose inclination, on the whole, depends upon the uneven and lawless slope of the earth's surface, in beds which present a very variable resistance, on account of the materials forming them. We speak here without reference to those places where the action of erosion is not yet complete, where therefore the bed is not formed by alluvial deposits brought to rest. We find such places, for example, where solid ledges of rock crossing the stream produce a raising of the bed, which, it is true, must eventually disappear through the eroding action of the water, but this will not occur for the periods of time practically in question. Such places always produce a break in the slope, and, moreover, a reduction above and an increase below.

Now, we usually find toward the mouth a reduction in the volume of deposit, so that, for this reason, the necessity of a fall decreases towards the mouth. But this reduced deposit undergoes just as much change of place as the surface-slope of the stream. The opinion is maintained by the writer that in finished reaches of rivers only a small part of the deposits carried down stream reaches the mouth; that, rather, the greater part remains forever motionless in the bed of the river at a comparatively short distance from its original location. Therefore, there is but a small part of the stony deposit present in the region at the mouth of completely finished rivers, which is not the product of the continuous attrition which the loose material, coming into the river above, receives on its way down stream. The greatest portion of these deposits is formed from, and corresponds in

size exactly to, the component parts of the diluvial and alluvial deposits which have been formed in previous times, and which form the depths crossed by the current. It is not in opposition to this theory that our large rivers annually carry immense quantities of mud and fine sand into the sea. Every loose particle which comes into the stream suffers a rubbing off, if ever so slight, in its motion down stream, the product of which forms a part of this mud. Besides this, the rain and high water flowing from the vegetable mold bring mud to the streams continually, which is carried in suspension to the sea. Only in streams or portions of streams in which the work of erosion is not yet fully developed, has the energy not yet been brought into equilibrium with the resistance of the bed. On account of the excessive fall, the energy is in preponderance; the desired equilibrium can only be attained by lessening the fall, *i. e.*, through a progressive scouring out of the bed, increasing from below upward. The loosened deposits are evidently transported for the whole distance where the whole bed is in a state of erosion, and only come to rest below the same. The deposits form a ridge down stream in the bed of the reach, which is made apparent by a backing up of the water, *i. e.*, a lessening of the slope up stream. Therefore, we have in succession three characteristic reaches in the course of the stream. In the first place, an upper one in which erosion is not yet complete, where transportation exceeds subsidence; a middle neutral reach where transportation equals subsidence, and finally, the lowest, where subsidence is greater than transportation. If, now, there is always a sufficient volume of water for the formation or maintenance of a certain energy, an uninterrupted transportation of deposit in the two upper reaches will occur. In consequence of the erosion of the bed in the upper reach, this transportation must continually diminish, as in connection with the raising of the bed below, which occurs at the same time, a lessening of the slope takes place, which is checked as soon as the resistance of the bed becomes equal to the transporting power developed by the fall.

In completed reaches of the stream, a condition of equilibrium exists which is temporarily disturbed only at high water; in the unfinished ones that condition is approximately reached. In the first case, the river flows on its own alluvion; in the latter, on a bed which is always deepening. Here the deposits on the bed suffer a change of position, which occurs within limited bounds of both time and space;

only that portion of the deposits which forms the upper stratum of the bed receives anew an impetus down stream at every high water. It remains at rest, therefore, between every two periods of high water, and hence a long interval of time is required before this portion reaches the mouth of the stream. Hence, this portion yields reluctantly to the eroding action of the water and the disintegration by attrition caused by mutual contact during transportation. In unfinished reaches of rivers all sediment that is set in motion must traverse the entire distance in which erosion occurs. It naturally undergoes a gradual decrease. But it must be emphasized that this law of the "wandering" of deposits and the lessening of it (when extended to all deposits) is true only of unfinished stretches of river. It should not be generalized of finished rivers, as is usually the custom at present, and against which G. Hagen has already raised an important protest. The deposits occurring in finished water-courses are but partially products by attrition of deposits formed in the upper part of the stream. They are, for the most part, products of the crumbling away of the banks of the same part of the stream in which they are found. The fact that both sediment and material rolled along the bottom are actually found in the lower portions would seem to contradict this, but these are doubtless brought into the stream at points far above the stretch undergoing erosion.

It is unfortunate that no reliable observations have been made which could help solve the very important questions relating to the origin, the course and the final resting place of deposits. The impossibility of following the silt with the eye during its wanderings prevents the observation and investigation of these transactions in Nature. It can only be confirmed by such observation as that, for example, a bank of deposit either retains its position permanently, or after a certain time has disappeared from a given place. It is only a supposition, not yet proved, that the bank of deposit newly formed down stream is formed of the same material as that which has meanwhile disappeared, having been loosened by the action of the water; that, in other words, one and the same bank has changed its place. In order to make this last an incontestable fact, one would have to bring forward proof that the deposits forming the second bank are indeed the same as those composing the first. This hint is all that is necessary to show the impossibility of a positive demonstration in Nature.

Therefore, nothing remains but to experiment on a small scale in order to throw light upon the phenomena. For this purpose the author has built a flume of zinc in the hydraulic laboratory of the Technical High School of Dresden. Clean sand of uniform size, but of various characteristic colors, was put into this flume in such a manner that colored alternated with colorless sections, the location of each of which was accurately established by measurement before being put in. A certain volume of water taken from the city supply was led through the flume in a steady stream, and the sand was set in motion by a certain inclination of the flume. It then became apparent that a movement of the sand along the whole distance occurred only when, by a comparatively great inclination of the flume, erosion of the sand-bed was effected. If the flume was given a smaller slope with a certain quantity of water and therefore a certain energy, only eddies were formed along the concave shore, which, as was mentioned in the beginning, set bed and shore in as tate of attack. The loosened grains of sand acquired but a slight motion down stream; they were precipitated, forming ridges which crossed the bed in arcs closing down stream, and in the shape of banks which were formed in the convex parts. After awhile, complete repose was reached in the sandbed—a sign that equilibrium between the bed and the forces of the stream was reached. More water was now introduced. The eddies in the pools again showed their effect in loosening and transporting the sand. The pools and inroads on the banks became deeper and wider; the loosened material came to rest, rolling over and then covering the deposits of the lower stage, and a new state of equilibrium was established. As the volume of water was diminished, the serpentine formation of the low-water bed inside the more direct high-water channel took place. But the contour of the channel had already conformed itself to the energy of the high water, so that when a greater quantity of water was again admitted, the effect of the increased energy was only apparent in the obliteration of the low-water formation by a slight and evanescent change of place in a small portion of the upper layers.

Numerous and careful experiments confirmed the fact that the characteristic traits of "finished streams are, that the surface-slope is in equilibrium with the shape and size of the bed, so that usually its form is in a state of rest, out of which, however, it is aroused at times when by a higher stage, a temporary disturbance of the equilib-

rium occurs, in consequence of the increased flow of water. In finished streams the moving power of the water undergoes no alteration with the same quantity of water, when disintegration is impeded by protecting the banks. With unfinished reaches the moving power constantly decreases with the steady decrease of slope.

When there arises the problem of regulating a river in the interests of navigation, *i. e.*, subjecting it to constructive treatment, without a loss of its natural characteristics, one must from the beginning preclude from such regulation the "unfinished" reaches last characterized. Regulation can only be successful in the case of "finished" reaches. Unfinished reaches can only be changed to a state of permanency with a stable bed, by canalization. A well-known example of an "unfinished" reach is the upper Rhine from Basle to Mannheim. Here the profile corresponding to a condition of equilibrium is not attained, as is evident by the ceaseless and progressive lowering of the bed. Hence, we find here a constant transportation of sediment down stream. It is true that erosion has been artificially developed by the marked shortening of the stream, which formerly had many windings. Only when the deepening of the bed has ceased, can further regulation lead to improved navigability.

Navigation has to contend with two principal evils: sharp bends, and lack of depth in the channels. We have explained how they influence and depend upon each other. We have seen that these irregularities, the removal or at least the alleviation of which appears necessary in the interests of navigation, are indicated by a variation in the surface-slope. As we regulate the latter, we regulate the stream itself. On the whole, however, one cannot alter the fall between given limits, as this has been produced in such a manner as to correspond to the natural features of the stream. One can only remove the local irregularities in the fall, *i. e.*, effect a local adjustment of the surface slope within these limits. As the irregularities in the fall are a maximum at the lowest stage of water, we may doubtless consider them as caused by the latter. If the slope is adjusted for low water, then, in a uniform and rationally formed channel, this will also obtain with higher stages of water.

Before we can consider the treatment of a low-water channel however, the "finishing" of that part of the channel above the low-water line must be completed—the conditions of the river-bed must have

adapted themselves to the change of energy caused by this finishing. The considerations upon which this finishing depends are—entirely in the interests of the regulation of rivers—the following:

As the river has an excess of energy during high water, everything is to be avoided in finishing the high-water profile, which would produce an increase of energy. A change of form into narrower and deeper ones of such natural high-water channels—which, as they have adapted themselves to the energy of high water, suffer but slight changes during that stage—is always connected with unfortunate results; because, on account of the increased energy, there occurs an increased scour of the bed; and because, therefore, large quantities of sediment are set in motion. It is true that in this way an energetic deepening of the channel takes place during high water, but after the high water, the sediment, which was in motion, settles, forming again, if not increasing, the irregularities of the bed. But navigation has always sufficient depth at high water; therefore, the deepening of the channel is of no value, being temporary and occurring only at high water. Where, therefore, it is necessary to build high-water dikes in the interest of agriculture, the river may be expected to show changes after the high stage; they are the inevitable and natural results of the excessive increase of energy at high water.

Every water-surface will find solid banks, at least at the places where the latter are attacked, in consequence of the formation of the ground plan of the stream. The next desideratum, therefore, is to reinforce the banks at the high water-line, or to construct new banks, strong and high. Between high and mean water, the river will usually overflow its banks, so that, to a certain height above mean water, when it is more or less full, the surfaces of its projections determine, for the time being, the lines of the shore. As strong currents cannot be formed on account of the slight depth of water over the projections of the shore, the requisite protection usually consists in a covering of grass and other plants. Only where grasses, etc., do not flourish is it necessary to protect the shore by traverses, which should be finished off at the level of the projection of the shore.

Where a stream is left to itself, the mean-water shore is formed by the natural boundaries of the true channel. Where a stream is to be regulated, we must endeavor to produce a uniform channel, where possible, by obstructing the subsidiary channels, so that for mean

water it will be impossible to avoid building new artificial banks at certain places. These must be constructed by strengthening in lines which lead to a uniform channel, and which, moreover, are connected with the existing natural lines where possible, so that they will be insured against disintegration, where such a thing is to be expected on account of the ground-plan of the channel. These lines are also dependent upon the relative distance apart to be given the banks during mean water.

As but one definite relation exists between the discharge of water, the size and shape of the cross-section, the surface-slope and the character of the bed, for the condition of equilibrium; and as this relation cannot be determined theoretically because of our ignorance of the laws controlling the interdependence of the very intricate motions of flowing water, especially as in a state of Nature we have always to deal with a variable velocity produced principally by internal motions; therefore, empirical methods are here best, saving one from more disappointments than the most profound speculation. "All theories assume an impossible stream," says Lechalas. Weber von Ebenhof expresses in a most apt way what is to be done: "The correctness of the cross-section is controlled by the true relation between the width of the channel and the depth of water in it; a relation which one learns best from the careful study of the natural profiles of unregulated rivers."

We may expect profiles to remain stable if we always employ good natural profiles on reaches of similar regimen, only when the original conditions under which they have been formed and maintained are everywhere the same.

The reaches which are well formed under the influence of the stream left to itself, and which remain well formed, always lie in such a manner that they are traversed by high and mean water in exactly the same direction. This is only possible when that part of the formation which is above high water is uniformly protected, preventing the breaking through of the banks at high water; or where the water breaking through at a high stage does not deviate from the direction of the mean water current. Such a section occurs usually at the apex of the concave bank and in such straight reaches as lie in the same direction as the current of the eroding high water. In all such reaches the operations of the high and mean water support each other; they are em-

phatically reaches of erosion in so far as the channel has, on account of this co-operation, buried itself comparatively deep They are, for the most part, therefore, reaches with a relatively weak fall which is smaller than the adjusted fall which is to be attained at that place under the most favorable conditions. Above and below that reach which has been well formed by Nature, breaks in the slope are found. When we construct uniformly a mean-water width peculiar to this reach on reaches of like regimen—*e. g.*, from confluence to confluence —the reach so treated will receive a certain degree of improvement, for as it becomes narrower an increase in velocity obtains. There results an unbalanced increase of energy, and, in consequence, a temporary disturbance of the equilibrium between the eroding power of the water and the resistance of the bed, which will only cease when the energy is reduced to its original value. But this is only possible through the scouring and deepening of the bed, as in only that way is a diminution in the fall produced, corresponding to the lessened necessity for fall on account of the more propitious profile formed, which we now find. A reduction of the fall can only be attained by a lowering of the up-stream water-surface. If the regulated reach joins one naturally well formed below the latter, then the fall of the natural reach will necessarily increase, and there will be also in the regulated section, as a result of regulation, a lowering of the water-surface and a reduction of depth. If the regulated reach lie above the typical natural reach, the original conditions under which the latter has been formed will also be changed. The fall in the regulated reach will be reduced by a lowering of the surface, and the water will enter the natural reach with an energy less than that existing previously. The internal movements causing a deepening of the bed are developed less in the natural reach than before ; the deposits, loosened by the scouring of the bed in the regulated reach, come partly to rest in the natural reach, raising the surface of the bed. This causes a raising of the water-surface in the natural reach above, and an increase in the relative fall below.

It is evident that we cannot develop good natural profiles uniformly by regulation which consists in entirely restricting the width. The ultimate effect of such regulation is, and can only be, that the line of slope, which was at first broken, is changed to one of more uniform slope. At the same time the reaches well formed by Nature necessarily undergo a diminution of depth. The depth to be attained will, there-

fore, always be less than with such good, natural profiles. We may approximately determine beforehand the depths to be attained during mean water, by careful and numerous measurements of the cross-section and leveling of the water-surface, and then determining the difference between the new line of slope which obliterates the irregularities in the fall and the adjusted bed. These operations are only admissible and sufficient for such reaches as are traversed at high water in a direction parallel to that at mean water. Where the two directions deviate from one another—and this is the case for all passages from one shore to the other—a restriction of the width at the height of mean water will not result in any marked deepening, because the passages crossing at high water would detrimentally affect their action at mean water. This is different in the concave bends. Here, the mean and high water assist each other and the deepening is permanent. The difference between the excessive depths in the concave bends and the shoals in the passage is greater than before. The variations in the fall of a serpentine stream remain, in general, unchanged. At all events, the full effect of the increased depth is of small account, because the bed and surface of the water are lowered simultaneously, so that the gain in depth is only the difference between these lowerings, which under certain conditions may equal zero.

The establishment of a narrower uniform mean-water bed gives the advance flood an especial advantage, as the water cuts out a deeper channel. In the more deeply cut channel, however, the irregularities in the slope at low water remain, in general, the same as before. Therefore, completion of regulation only by restricting the width of the mean-water bed will not furnish that degree of navigability which may be attained.

When, on the other hand, the advocates of this system point to the results, substantiated by figures, which have been actually achieved in many rivers, we have to say that these results were quite inevitable, because they selected for regulation, rivers wholly uncontrolled, with many islands, branches, etc., and because in place of the channel, which was split up into many branches, they provided a uniform conduit by the obstruction of the branches, in which, naturally, a much greater depth must obtain than in the original stream. If, however, a river is regulated in this way, a decided increase in the depth by further restriction of the width cannot be brought about. The wilder a stream

is, the easier it is to accomplish great results by regulation with restriction of width; but the more a uniform water-course is formed by building out the banks and obstructing the side channels, the harder it is to attain a greater depth by a further application of the system of the restriction of width. It is easier to make a wild river double its depth than to deepen a regulated river by a few centimeters.

The mean-water shores extend into the stream-bed either with a comparatively uniform slope—this being the case with concave shores which should be built out with the flattest possible slope—or, at the convex shores, a flat bed of sediment is deposited, either directly or indirectly, at a comparatively slight depth. As the upper surfaces of convex shores are exposed to the injurious cross-currents of the higher floods, they are to be reinforced by traverses whose strengthened tops do not rise above the surface at the highest point, but project in a gentle and uniform slope out into the stream-bed. These traverses, which are to be firmly connected at the land end with the mean-water shore, bound the low-water shore, which follows here the natural ground-plan of the beds of deposit, at low-water level; but at the same time, the irregular boundaries of the latter are to be evened off by the most easy and regular curves. Reinforcement of the steep concave shores completes the protection of the shore in the curve. The low-water width, which is here present and protected, is to be completed uniformly. A further restriction of the width of the low-water bed, assuming that such would not hinder navigation, would lead to a double profile for mean water, a form not assumed by good natural mean-water profiles, which latter should be striven for, and reached under favorable conditions.

The bottom of the channel will still show a succession of pools and shoals corresponding to the conformation of the ground plan. We have only procured a channel as uniform as possible whose shores are protected against the attacks of floods rising above low water. The real work of regulation is now to be undertaken, the removal of the irregularities in the fall. Here we must establish an increase of fall over the pools, and at the same time a decrease of the same at the passages over the bars below the pools. This is to effect a greater depth at the bars so that the inherent energy of the flowing water will be retained as much as possible while passing the work-consuming pools. Three factors are met in the bends which absorb energy, as explained

in the beginning: (1) change of direction; (2) change of form, and, moreover, an enlargement of the cross-section, and (3) the loosening and transport of deposits. The change in direction must, in general, be retained. By flattening the curves, which are too sharp, the effect of (1) can be diminished by a small amount. There remain, therefore, the artificial influences brought to bear on (2) and (3). So far as the former is concerned, the profile, which is deepened and widened on one side, is to be changed to a flatter one of more symmetrical form by raising the bottom of the channel. But, in order to render this new profile permanent, it is necessary to make the new bed firm. Both are to be attained by submerged dykes, which must cross the bed at alternate intervals to be empirically determined, on the one side over to the traverses projecting with a gentle inclination from the convex shore, and on the other side connected to the steep concave shore at low-water level by a flat slope. The water-surface will be raised in the pools by this raising of the bed and change of form in the cross-section. As this raising of the water-surface approaches the original surface-line upstream in an asymptote, as in a back-water curve, the depth of the water will, at the same time, be increased with the reduction of the excessive fall on the bar above. This increase in depth is still further augmented by the water emerging from the bend, this being possessed of a greater energy than before, because of an increased slope, attacking the bar in the bed of the channel down stream, and so far lowering it that a new condition of equilibrium is formed corresponding to the increase of energy. Should the strength of the current be insufficient for this, we can remove the bars by dredging the material without danger of its reappearing, as the cause—the energy-consuming work of the pools—has ceased to act. The loosened deposits are caught in the ridges of the next pool below, thus turning it into land.

With reference to the increase of depth, we can predict, if only approximately, the result to be expected under the most favorable conditions, by starting from the new line of slope which evens off the irregular low-water line of surface-slope and seeking the difference between it and the corresponding adjusted line of the longitudinal profile of the bed at the thalweg. The latter also determines the height of the bars. Mathematically, we estimate the depth d to be attained in the following manner:

Assuming the two known equations—

$$Q = w\, d\, v \dots\dots\dots\dots\dots\dots\dots\dots \quad (1)$$

$$v = k \sqrt{d\, i} \dots\dots\dots\dots\dots\dots\dots \quad (2)$$

in which d and v (velocity) are unknown, Q (volume of water) is to be determined by measurement, w is the natural low-water width of the surface in the required mean-water bed, to be measured in the apex of the bend; i is the adjusted rate of fall attainable. It suffices to determine k approximately from the equation—

$$k = \frac{v}{\sqrt{d\, i}}$$

in which we give a value to the right-hand member to be established by measurement in the low-water channel existing in good natural reaches.

From (1) and (2) we obtain the equation—

$$d = \left(\frac{Q}{w\, k \sqrt{i}}\right)^{\frac{2}{3}} \dots\dots\dots\dots\dots\dots \quad (3)$$

This equation shows that d decreases in the pools, because the slope i increases while w is unchanged; further, that d increases on the summits of the passages as a decrease of i takes place, in consequence of the uniform establishment of the natural low-water width in the apex of the bend, and therefore a better concentration of the water, and also from a decrease of w.

On the basis of the foregoing discussion, the answer to the question forming the theme is given in the following conclusions :

(1) Only rivers or long reaches of rivers in which natural erosion is fully developed are adapted to regulation. The navigability of unfinished rivers, yet in a state of erosion, can be improved with permanent results only by canalization.

(2) The most that can be accomplished by regulation is the desired adjustment of the slope of the low-water line, and this only on reaches of uniform regimen and uniform characteristics.

(3) This feasible adjustment of the slope, to be accomplished when the conditions are most favorable, can only be established and brought about by constructive measures after formation of that part of the channel which rises above low water is completed ; after the conditions of the bed have adapted themselves to the change of energy caused by the formation of the mean and high water bed—in other words, after the erosion caused by this formation has come to rest.

(4) To secure the establishment and permanent preservation of the adjustment of slope, the irregularities of the bed in the longitudinal and transverse profiles are to be adjusted after reinforcing the low-water shore, and the bed is to be strengthened where attacked by the water on account of the ground plan of the channel. Restriction of width alone will not bring about that degree of navigability which may be attained.

(5) The maximum depth of water to be maintained during low water is then determined by equations (1), (2) and (3).

The writer has thus reached the conclusion of his demonstration. Those who, on account of the title, have counted on an exposition equipped with great mathematical and speculative apparatus, who have expected that the question propounded would be solved in an abstract, theoretical manner, will be disappointed. But it can be assumed that there are not many such, that the majority will acknowledge without further question the truth conveyed in the words already quoted: "All theories assume an impossible stream." The writer's only wish is to show that under certain premises, but only under such, an answer to the question propounded is possible. He is well aware, however, that with regard to this indispensable hypothesis, it is in Nature—in practice—never to be entirely reckoned on. Thus, for example, complete stability of the bed will never obtain during high water; it will not obtain so long as tributaries which are in a state of erosion discharge silt into the main stream, so long as disintegration of the banks occur. Even the introduction of suspended particles of the soil after every heavy rain and every flood will make absolute stability of the bed unattainable. We can, therefore, simply ascertain approximate values.

Furthermore, it is well known that in practice many considerations, for the most part reasonable, render the rational construction of a channel unfeasible. We can rarely remove irregular dikes running beside the stream, or injudicious and obstructing habitations. We must then pursue the best course possible, *i. e.*, in spite of such circumstances, we must regulate only the low-water bed and endeavor to keep it in good condition by means of maintenance, such as dredging.

The subject was suggested by the transactions of the Third International Congress of Inland Navigation at Frankfort-on-the-Main in 1888, at which—conformably to a motion of Professor Schlichting, of Berlin—

the necessity of attempting to establish the degree of navigability of water-courses which may be attained, was unanimously acknowledged. It is very greatly to Professor Schlichting's credit to have brought this necessity into prominence. G. Hagen has declared in his book on constructive hydraulics, that there are no bounds to the demands by the public who make use of the water-ways for the navigability of rivers; while the natural formation of rivers entirely prevents the extension of their navigability beyond certain limits. Certainly the complaints of ship-owners of the poor character of our water-courses will not cease, until hydraulic researches have determined what degree of navigability can be attained by regulation under the most favorable circumstances.

If we wish to attain a greater depth than is possible by regulation, the only method is by canalization. Let us hope that a further exchange of ideas and a further clearing up of the question may result from the foregoing discussion, which exchange would appear the more to be desired the more it is recognized in what difficulties we are involved on all sides wherever this question arises.

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THE IMPROVEMENT OF HARBORS ON THE SOUTH ATLANTIC COAST OF THE UNITED STATES.

By WILLIAM MURRAY BLACK, Captain, Corps of Engineers, U. S. A., M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

In the following paper the writer has attempted to show the general conditions of the coast, the forces acting and their effects, and then to give a history of a few of the more advanced works, with remarks on such engineering features as he thought of general interest. The paper is, from its nature, more or less a compilation, and the

NOTE.—In his studies on the subject, the writer has received much aid from the following books: Harcourt's "Harbors and Docks," Stevenson's "Construction of Harbors," Mitchell's "Reclamation of Tide Lands" and "Tides and Tidal Phenomena," Gilbert's "Topographic Features of Lake Shores," Bache's "Atlantic Coast Tides," and, most of all, from the reports of the various officers and assistants of the Corps of Engineers, U. S. A., published in the annual reports of the Chief of Engineers. To all of these authors he desires to express his indebtedness.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

writer has quoted freely from published works, preferring to give the exact words of the authority when possible.

The southeast Atlantic Coast harbors of the United States belong to the troublesome "harbors on a sandy coast" which have been so long a cause of worry to engineers and governments, and which so often obstinately refuse to "stay put" after much money and time has been spent on their improvement. Maintained and destroyed by the same power, the ever-restless sea, their formation and maintenance depend on so nice an understanding of the forces at work, and so nice an adjustment and control of these forces, that it is not strange that disappointment has frequently followed so much painful effort.

The creating and destroying forces are the sea and the winds; their instrument, the sand. These are never at rest, and it is the problem of the engineer so to control and guide them as to cause them to build the protecting beach, or to deepen the desired channel, and having finished their work, to pass harmlessly by the harbor they have formed.

The winds act on the sand directly and through the medium of the sea. Their direct action is to transport vast quantities of sand over the level surface of the beach, or to roll along the dunes already formed. By sand catches, sand fences and plantations of beach grass this movement can be controlled and turned to useful ends. On a dry beach during a brisk gale, the whole surface is in motion. On the Florida coast the sand moves like drifting snow, with a depth of 4 to 8 ins. A properly constructed sand catch on that coast can form a dune 10 ft. high in a single year. The resultant movement is in the direction of the prevailing gales. It would be difficult to estimate how great a factor in the formation of the bars across the openings in the coast line this movement is, but its effect must be very large.

The indirect action of the wind on the sand beach is through the waves. The coming of a gale is frequently heralded 36 hours in advance by heavy rollers. During the gale, the wave height is reduced; but the surface velocity of the water (and its erosive action) is greatly increased. After the gale has passed, the waves again become higher and make up in battering power for the loss of velocity.

Wave crests approach a coast in lines perpendicular to the direction of the wind. As each wave feels the bottom, its advance is retarded. The line of wave crest which originally had approached

the coast diagonally, swings around and finally breaks on the beach in a line more nearly parallel to it.

Wave form, velocity and energy have long been studied, but the greater portions of the investigations have been made under conditions radically different from those prevailing on our sandy coasts and are of but little immediate practical use there. According to Scott-Russell and other authorities, the form of oscillating waves is that of a prolate cycloid, which changes to a common cycloid just before breaking. "Hagen * * * * showed that the line which unites points which are in the same phase of a revolution is a prolate cycloid, which becomes more prolate as the depth increases, and at the surface approaches a common cycloid. Weber Brothers and Rankine state the orbit of each particle to be an ellipse, while Froude, Scott-Russell, Hagen and Gerstner state that this orbit is a circle. When the wave enters shallow water the general opinion seems to be that the orbit is always elliptical."* According to Stevenson the height of a wave crest above the mean level of the water is two-thirds of the wave height from hollow to crest, and waves break when they enter water whose mean depth is from once to twice the wave height, breaking earlier when the bottom shoals rapidly than when the slope is gradual. Stevenson gives much interesting data on the relation of fetch to wave height, etc., but with the very gentle slope of the bottom along our southern coast, the storm waves of the Atlantic are broken and reformed long before the beach line is reached. He gives the velocity of the longest waves on the Atlantic Ocean as 115 ft. per second, and of ordinary storm waves as 50 to 60 ft. per second.

Of greater immediate value in the present discussion are the investigations of Lt. D. D. Gaillard, Corps of Engineers, on the force of waves on the Florida coast. Lieut. Gaillard's conclusions may be condensed as follows: Waves with the form of a common cycloid have an energy in foot-pounds for each foot in length measured along the crest, and for that portion above a horizontal plane tangent to the hollow, equal to 6.3 h^3, in which h is the height in feet from hollow to crest. The application of this formula is expressly limited, and is useful mainly in comparing the relative exposure of two places where shoal water extends for some distance seawards and where the fetch of the waves is practically unlimited.

In shallow water, immediately before breaking, for waves varying

* Lt. Gaillard, Rep. Chf. of Engrs., 1889-II-1319.

in height from 2 ins. to 7 ft. (hollow to crest), the observed relation between wave height and velocity is expressed approximately by the formula $h = .08242\, x^{\frac{3}{2}}$, in which h is the height / in feet, and x the velocity in feet per second.

These waves broke when they arrived at depths, which, when the water was undisturbed, were from $0.72\,h$ to $2\,h$. For the great majority, h equaled d (depth of undisturbed water) at breaking. For a given locality the variation in the ratio of d to h seemed to be caused by the direction and force of the wind. A strong wind in the direction of wave motion made $d = 1.25\,h$. A strong contrary wind made $d = 0.72\,h$. With no wind and a uniform bottom with a slope of 1 on 100, d equaled h. With a slope of 1 on 12, d sometimes equaled $2\,h$.

Observations on waves varying in height from 2½ to 6 ft. showed that the height of wave crest above the mean (undisturbed) water surface varied between $0.67\,h$ and $.89\,h$, with a mean value of $0.76\,h$. A gently sloping bottom or an opposing wind increased the height of crest; a steep slope or a favoring wind decreased it.

"Considering only a well-defined wave, breaking in water of a depth equal to its height from hollow to crest, the maximum effect (recorded by dynamometer readings) was found at a distance above the water surface equal to about $\frac{1}{10}$ of the wave height, from which point it decreased to zero at a distance above the water surface equal to about ~~one~~ / three-fourth of the wave height."*

In all this discussion the distinction between velocity of wave propagation and the velocity of translation of the particles of water in the wave must be kept clear. McAlpine showed by experiments with a tank of fresh water that when water was added suddenly at one end, the effect was felt at the other end by a wave long before the actual movement of translation was transmitted to the water there. The velocity of wave propagation was to the velocity of transfer of the water as 1 is to .09. This is constantly seen in our tidal rivers. In the Savannah River the rate of propagation of the flood tidal wave varies from 12 to 16 miles per hour, and the maximum velocity of the flood current is 1.4 miles per hour.

The wave which in a deep sea is a simple undulation, excepting where its surface is thrown onward by the wind, changes in shape as the shallow water is entered, and the energy of undulation is transformed, more or less completely, into a force of translation, according

* Lt. Gaillard, Rep. Chf. of Engrs., 1891-III-1637.

as the entire wave, or only a portion, breaks. The final break occurs where the incoming wave meets the rapid first backflow of its predecessor from the beach.

"It is a familiar fact that waves running over shallow ground acquire a real motion of translation. The passing of a wave, as felt by divers standing upon the bottom, is a sudden jerk toward the coast. The water that would thus pile up against the shore is carried back into the ocean by a gentle and continued current. The movement toward the land is in very short, but very rapid, dashes, while the return is more gentle and steady. In this contrast of velocities between the onset and the retreat of the sea lies, I think, the true cause of the accumulations upon the coast and the tendency of heavy bodies, like the coal from steamers, etc., to come on shore. When we consider that the work done is proportional to the square of the velocity and that the weight that may be moved by running water varies with the sixth power of the velocity, we certainly may expect the changes along the coast to reflect rather the action of rushing waves than feeble currents."*

A heavy gale heaps up the waters on the lee shore when the wind and wave action is oblique to the coast line. This heaping up of the water gives rise to a current parallel to the beach and close in shore, generally within the first line of breakers.

The effect on the sand may now be noted. In experiments made during the construction of the Brooklyn Bridge, Mr. Collingwood found that when sand was thoroughly mixed with the water, 40% in bulk was carried when the velocity exceeded about 22 ins. per second; when the velocity was less, a deposit was made. Colonel Elliot, in his report on the improvement of the Harbor of Nantucket, assumes that a velocity of 1.25 ft. per second is sufficient to produce a scour on a bottom of gravel and sand, and quotes the following authorities: Debauve, 0.5 to 1 ft. per second; Login, 0.67 to 1 ft. per second; Weisbach, 1.25 ft. per second. The writer has seen a bank of packed fine sand stand without loss under a velocity of 3 ft. per second, but melt away when that current was accompanied by the slightest wave motion. It may be accepted that sand in suspension may be transported by a current too feeble in velocity to lift it from its bed.

As the successive waves approach the shore, there is a slight and continuous motion of sand beneath them; and this sand, lifted by the waves, is moved shoreward by the breakers, and during on-shore gales, parallel to the coast by the littoral current induced as previously

* Mitchell, "Reclamation of Tide Lands."

described by storm action. Arrived at the steep slope of the beach, the wave breaks with great force, and its water, loaded with sand, rushes up the slope, approximately in the direction of the wave approach. A portion of the load of sand is deposited at the limit of wave action; the remainder, picked up again in the back rush of the water, is carried back directly down the slope, only to be moved further along the beach by the next wave.

A thorough analysis of wave and current action on coasts is found in Mr. G. K. Gilbert's interesting paper on "The Topographic Features of Lake Shores." This action may be summarized as follows: The agitation of the waves and the transporting power of the waves and undertow accomplish a sorting of the coast detritus. The finer portions are carried out to deep water; the remainder, clean sand and gravel, is left as shore drift, and the zone occupied by the shore drift in transit is the beach. It extends from beyond the line where storm waves break, to the shore line reached by the highest waves. The general profile is such that at each point the slope represents an equilibrium in transporting power between the breakers and the undertow. Where the undertow is relatively potent, the slope is gentle. Where the relative power of the breakers is greater, the slope is steeper. "The result is a sigmoid profile of gentle flexure, upwardly convex for a short space near its landward end, and concave beyond."* The outer bar of our coasts shows the first point of breaking of the storm waves.

Where the coast line turns abruptly landward, it cannot be followed immediately by the littoral current. Along the inner edge of this current, after passing the point of the shore line, velocity is reduced by the still water of the bay, the drift is deposited and a spit is formed. Where the littoral currents are of wind origin, they are intermittent. Then the materials of the spit may be spread by the currents to and from the bay, forming a bar like those off our southern coast entrances; where the spit is kept high enough to hold the transverse currents at its end, a hook is formed which, by a change of direction of the transverse current, may become a loop.

In all this littoral movement, the relative eroding and transporting powers of storms and calms are to each other as the similar powers of a stream during floods and low water. Movement on the coast is continuous, and the features of the coast show the resultant of all the action.

* Gilbert.

Stevenson and Harcourt give numerous examples of the power of waves in deep harbors and exposed situations. Examples of wave action on our own more protected coasts and in our shallow waters are not so numerous. In the report to the Chief of Engineers of 1890 on the Improvement of St. Augustine Harbor is the following:

"A wave may act on the jetty directly, by a blow, or a push, or a blow and a push combined; and, indirectly, by a pull, by compressing the air in the voids of the masonry, by upward pressure due to the difference of head produced on the two sides of the jetty, or by a combination of these actions. The direct action measured on the dynamometers had effects equal to pressures varying between 190 and 753 lbs. per square foot. This action took place when a wave broke directly on or in advance of the jetty; this also compressed the air in the voids of the jetty. * * * * Jets of water and sand were sometimes projected up from the cracks in the jetty to some height. The maximum height of any wave observed striking the work was 6 ft. * * * * Up to a height of about 2 ft. above mean low water, rip-rap weighing 40 to 50 lbs. was but little disturbed. Above this limit, to the height of 10 ft., the highest point observed, rip-rap varying in weight from 40 to 200 lbs. could not be held at any slope. An isolated piece of concrete weighing 350 lbs. and resting on its flat base 4.7 sq. ft. in area, with its center of gravity 7 ft. above mean low water, was moved several feet by breakers whose crests were about 7½ ft. above mean low water. These breakers measured 3½ ft. from hollow to crest. * * * * All that portion of a mound or wing, composed of rip-rap (varying in weight from 40 to 220 lbs.) tightly chinked with oyster shells, lying between 4 and 6 ft. above mean low water, no matter what side slopes the rip-rap was given, would be carried away in a single tide whenever breakers greater than 4 ft. in height struck it fairly. * * * * A block of concrete weighing 527 lbs. was elevated 1.3 ft. by the action of a single breaker. During the same tide it was moved 23 ft. inshore. A dynamometer within 8 ft. of its original position recorded a maximum pressure of 575 lbs. per square foot during this tide. A piece of concrete weighing 200 lbs. was lifted vertically to a higher level than that of the water surface by a wave which broke just in front of it. Another block of concrete weighing 1 600 lbs. was lifted from its bed vertically at least 14 ins., and then moved several yards."

Later, a concrete block 10 x 6 x 2½ ft. and weighing dry 21 000 lbs., lying about at the mean low water-line of the beach, was lifted vertically 3 ins., and there caught and held fast. The maximum wave height and dynamometer reading during that gale were 5.5 ft. and 633 lbs., respectively.

Another familiar effect of wave action was shown at Sandy Hook

where a line of rip-rap placed at the ordinary high water-line, composed of blocks weighing from 300 lbs. to 3 tons, was undermined and sunk into the sand from 4 to 6 ft. It may be stated generally, that where an obstruction is placed on a sand beach between high and low water, if it is too heavy to be moved, the resultant effect will be to smooth off the beach, either by sinking the object, or by building the beach over it.

Currents.—Having considered the mode of action of the sea by waves, there now remains the second form of attack—by currents. The eroding action of running water is too well known to require description, and the following principles only will be noted: First, the eroding power of water varies with the square of its velocity; second, feeble currents will transport material which they are powerless to lift from its bed without the help of some stirring action.

When a shoal of shifting material is crossed by tidal currents, as a rule the flow does not take place in any one channel to an equal extent in both directions. The slope of the bottom of the channel will show the direction of the maximum flow. Thus, flood channels have a gentle bottom slope up from the sea, with the least depth and steepest slopes at the inner ends. Channels in which ebb currents predominate have their least depth and steepest bottom slope at the sea ends.

There is another variety of sand movement which has been but little investigated, and the causes of which are somewhat obscure. It is well known that the surface of sand beaches and shoals varies in compactness to a marked degree from time to time. As generally stated, at times the sand is "alive," and the whole surface is soft and shifting. On the beach, between high and low water-lines, this may be a function of the dryness of the sand. At St. Augustine it was also found to vary with the time elapsed since the last deposit on the surface was made. After a gale, the new beach made during the gale would be very soft until it had been pounded down by the breakers of several tides. In shoals covered at all times by water, it is the general opinion, well supported by evidence, that the sand surface is alive during floods and more compact during ebbs. On the other hand, in investigating this subject at the mouth of St. Johns River in 1889, Mr. Bacon found that the maximum volume of sand actually in suspension close to the bottom of the bar channel during ebbs was three times the maximum flood volume.

A typical example of sand movement on the bottom (not in suspension) under the action of currents is found in the report of Mr. J. W. Sackett, United States Assistant Engineer, on his survey of the northwest entrance to the harbor of Key West. The sand there is coarse and light, and over 97% calcareous, being formed from disintegrated coral rock. A cubic foot of the sand, dry, settled by shaking, weighed 80 lbs. and contained 50% of voids. The grains varied in size from 0.005 to 0.08 ins. The water was very clear, and the bottom was plainly visible with the aid of a sponger's "water glass." The observations were made in depths varying from 7 to 17 ft. The coarser sand was always found where the velocities were the greater.

"We observed that the wave crests were at right angles to the direction of the currents. The wave length seemed to increase as the velocity of the current increased, until the maximum velocity was attained, when the wave length in feet was about two-thirds the current velocity in feet per second. It then remained about the same until the current changed its direction, when the waves would become obliterated. In the course of about half an hour after the current had assumed a definite direction, the waves were reformed correspondingly. The rate of advance seemed to be about one-fiftieth of the velocity of the current. The slope of the side toward the current was about 1 on 5; on the other side, it was about 10 on 4. At no time during these observations did the current velocity exceed 1.5 ft. per second." * * * * "On the sand bores * * * * the sand is quite coarse, and while passing over them in about 7 ft. of water, with a current setting across them to the south, probably less than 3 ft. per second, sand waves were seen as much as 7 ft. apart and 1 ft. high, and the sand seemed to be all in motion."* In rough weather this sand is so stirred up that the water over the shoals assumes a murky hue.

Coast Line, Plate I.—The portion of the coast under consideration extends from Cape Hatteras to Cape Florida. In 1857 Professor Bache drew attention to its bay-like form, and to the effect of this form on the tides within its limits. A line tangent to the two extremities has a bearing N. 21° E. Its length between tangent points is 700 miles. The maximum depth of the bight, measured at right angles to this line, is 200 miles, and is found in the neighborhood of Sapelo Sound, opposite the middle point of the tangent line. "The tidal wave setting into the southern bay rises as the bay contracts, and the heights of the tides along the shores increase as the places are more distant from the chord spanning the entrance." The bay-like formation is shown also

*Rep. Chf. of Engrs., 1890-II-1595.

in the slope of the bottom, which becomes flatter as the head of the bight is approached.

Seen from the sea, the shores of the southern bay present a monotony of scenery broken only by the openings into the many bays and inlets; everywhere is the sand beach backed by dunes over which a scant tree-growth shows. The highest land along the coast between Cape Florida and the highlands of Navesink is Mount Cornelia, at the entrance to St. Johns River, 60 feet high. The sand beach is continually in motion, with a resultant movement to the south. The source of the sand supply seems to be the New England coast. On the New Jersey coast the sand is coarse, with frequent beds of pebbles. To the south the pebbles disappear and the sand grows finer, until, at St. Augustine, 1 grain in weight of sand contains 2 050 particles, with an average diameter of .005 inches, and beds of broken shell are of frequent occurrence. South of Cape Canaveral tropical shells begin to appear in numbers on the beach. South of Cape Florida the silicious sand, which has been found all the way down the coast, begins to be mixed with beds of calcareous sand from disintegrated coral, and further south still the silicious sand has disappeared entirely, and calcareous sand alone is found.

The mean slope of the beach between the mean low water-line and the 3-fathom contour of the sea bottom is 1 on 45 off Hatteras, and decreases regularly to Sapelo Inlet where it has become 1 on 1 000. It then increases to Canaveral, where it is 1 on 55. The deeper contours show the same regular flattening in the bight. At each opening the regularity of the beach is broken and the contours, from 1 to 5 fathoms, are pushed out, to inclose an irregular fan-shaped area, or "bar," crossed by one or more shifting channels from the entrance, which generally incline more or less to the south.

The rivers emptying into the bays and inlets, or directly into the sea, have but slight slopes in their lower courses and are tidal streams for many miles from their mouths. The sediment brought down from their headwaters is deposited almost entirely in the interior basins. The amount reaching the coast is too small to be appreciable.

Whatever the problems arising in the interior improvement of the various harbors may be, the problem at the entrance is everywhere the same—how to control the moving sand. To do this, the nature and cause of the movement must be understood. To this end the action of the controlling forces, the sea and the winds, must be investigated.

Currents, Winds and Waves.—In his paper on the southern bay, Professor Bache continues:

"Beginning at Tybee entrance, Fort Pulaski, Savannah River, we have a good series of tidal stations to Hatteras, five in number. * * * * The mean co-tidal hour is 11 hours 52 minutes, and the angle which the co-tidal line makes with the meridian is 52° 9′, agreeing very nearly with the trend of the coast. * * * * The motion perpendicular to the direction of the co-tidal line is 24 miles in half an hour, agreeing very nearly with the velocity due to depths." * * * * "Group F is at the extreme southern portion of the series, where the tide wave is turned by the Bahama Banks and makes its way through the Straits of Florida. The three stations of this group are Cape Florida, Cape Canaveral and St. Johns entrance; of this, Cape Canaveral affords but a vague result. The co-tidal line makes an angle of 117° 12′ with the meridian, and the motion in half an hour is 29 miles" (see Plate I).

The positions of these co-tidal lines show an absence of any marked tidal currents along the coast. This might be expected, for, as stated by Prof. Henry Mitchell: "Tidal currents are rarely visible far from land, since they are called into activity by the delays and distortions of the tide wave consequent upon the resistances of shoals or confined and shallow channels." Corroborative proof of this absence of marked tidal currents is found in the statements of captains of coasting steamers to the effect that the direction of the currents depends on the direction of the wind; in the experience gained in the attempt to sink the caisson for the new Hatteras light, when currents were observed from some direction about all of the time, but shifting with the wind and totally independent of the tidal changes; and in the current observations off the Florida coast at and near the mouth of the St. Johns River.

As the tidal wave approaches the coast, when not influenced by the wind, the water rises nearly simultaneously all around the fan-shaped shoals off the entrances and pours into the interior tidal basins, gaining marked velocity and direction only after attaining the well-defined channels. Outside of these confined channels, the currents due to tidal action are too feeble to have any appreciable effect on the sand movement of the coast. This forms one of the many differences between the problems of our coasts and those of the narrow seas abroad.

The Gulf Stream is too far from the coast north of Cape Canaveral to have any known effect on the sand movement. Other currents are

at times observed close in shore with high velocities and generally northerly in direction, but their effect on the sand movement is slight. The great and marked changes on the coast are due to storm waves and currents, and the direction of the movement results from the direction of the wind. The resultant movement is in the direction given by the heaviest and most prolonged gales.

Winds.—At Hatteras and below, winds from northeast and east will produce a southerly, and from the southeast and south a northerly, movement of sand and currents along the coast. The reports of the Weather Bureau show that from 1886 to 1891, inclusive, observations made three times daily at Hatteras gave 1 333 observations of northeast and east winds and 1 045 of southeast and south winds, with the heaviest gales from the north. For Charleston, S. C., the numbers become 1 426 and 737, respectively. Further south the prevailing summer breezes are from the southeast. On the Florida peninsula, winds from the north and northeast give a southerly, and from the east and southeast a northerly, movement. At Jupiter Inlet the record from 1889 to 1991 gives 476 from north and northeast and 906 from the east and southeast. Nevertheless the sand movement along this coast, under the controlling influence of the northeast gales is also to the south, as shown by the reports of the engineers in charge of the works at Cumberland Sound, St. Johns River entrance, and St. Augustine.

Thus, in his project for the improvement of Cumberland Sound, Gen. Gillmore states—

"There is no evidence of a prevailing littoral current, although the Coast Survey chart shows that the flood produces a northern and the ebb tide a southern current along the coast. The shifting character of the bar is due to the combined and ever-varying action of winds, waves and tidal and storm currents. There are no tables of records, so far as I know, showing the duration and intensities of these agencies; their relative influence, therefore, can only be inferred from the observed magnitude of the results produced, and these point to the superior aggregate force of northeast winds, and the waves and currents produced by them."

Lieutenant Rees, reporting in 1892 on the survey of Brunswick outer bar, states that the resultant direction of the forces that move the sand and mold the shoals at that place is toward the south, and that the winds which produce a sortherly movement of the sand are to those that produce a northerly movement as 29 is to 16.

This general sand movement along the coast must not be con-

founded with the local movement along the beach at each harbor entrance. As a general rule, unless the ebb currents are directed close along shore outside the entrance (as at St. Augustine, Fla.) there will be a local beach movement of sand toward the entrance at each opening in the coast line. This movement takes place generally during the rising tide, under the influence of the advancing waves and tidal currents of the entrance. In some instances, where the volume of flow through the entrance is great, there is a constant local littoral current of small velocity toward the entrance from both sides. During the flood inflow it is a part of the general movement of the water toward the interior tidal basin. During the ebb outflow it is from the eddy produced by the friction of the swift ebb current from the entrance on the still waters outside. This current undoubtedly has some influence in massing the sand on the two sides of the channel.

Under the forces acting, the sand of the open beach is always shifting, but the main features remain practically unchanged. At the openings in the coast line, the advancing sand continually tends to push the channels to the south. This southerly movement continues until the channel between the tidal basin and the sea becomes too long and the slope too slight to permit a velocity sufficient to equalize the difference of head at each tide. Then, frequently aided by a storm, the waters break a new and more direct channel, which, in turn, is pushed southward.

The general conditions prevailing on the portion of the coast under discussion may be summarized thus :

First.—The shores are low, fringed by a beach of light, shifting sand; the foreshore has a very gentle slope, giving comparative protection from wave action.

Second.—The heaviest and most prolonged gales are from the northeast, with occasional severe gales from the southeast.

Third.—The mean tidal range is from 1.5 to 7 ft., with two tides daily.

Fourth.—There are no continuous strong littoral currents, and no strong tidal currents excepting in the immediate vicinity of the openings on the coast line.

Fifth.—The coast storm drift of sand is large in volume with a resultant movement to the south.

Sixth.—This drift forms fan-shaped shoals across all openings on the coast line.

Seventh.—There is little or no fresh-water sediment brought to the coast line.

Eighth.—The channels across the shoals are generally shifting in character, and the navigable channels are maintained by the ebb outflow from the interior tidal basins, reinforced by the fresh-water discharge from the interior.

Improvement of Entrance to Cape Fear River.

A line drawn tangent to the coast of North and South Carolina at the head of the bights called Onslow Bay and Long Bay, respectively, will cut off a piece of land shaped like an isosceles triangle, with the equal sides somewhat concave (see Plate II). Cape Fear forms the vertex of the triangle, and Wilmington, N. C., lies a little beyond the base, about one-third of the distance along the base from the north point of tangency on Onslow Bay. The branches of the Cape Fear River unite in the vicinity of Wilmington. Just to the south of the imaginary base the river suddenly increases its width to one mile, and from that point to the sea it has the shape and characteristics of an estuary.

After passing Wilmington the direction of the river is nearly due south, and it holds this course until at Federal Point, 10 miles north from the extremity of Cape Fear, it is separated from the sea only by a narrow beach of ½ mile width. There it turns slightly to the west, and, passing parallel to the coast, empties into the sea to the south of Cape Fear, 5 miles from its point. From Federal Point, for 6 miles, the barrier between the river and the sea is a narrow beach, 100 to 200 yds. wide, between which and the river channel are shoals from 1 to 2 miles broad. Then the barrier widens into a lozenge-shaped piece of marsh, known as Smith Island, with high ground on its southern face. Cape Fear forms the southern and sea point of the lozenge. Baldhead Point, its western angle, forms the eastern bank of the mouth of Cape Fear River. A higher point of sand between Federal Point and Smith Island is known as Zekes Island. Cape Fear is prolonged seaward for 17 miles by the Frying Pan Shoals, on which the depth varies from 7 to 16 ft. Appearances would indicate that the mouth of the river at some time had been near Federal Point, but that the coast sand movement had formed a bar and deflected it to the south, where it found a more sheltered mouth behind the obstruction which formed Smith Island and the Frying Pan Shoals. In its

present condition this strip of beach, with Cape Fear and the Shoals, form a natural jetty, which has enabled the river to maintain, unaided, a 14-ft. channel to the sea.

The distance from Wilmington to Baldhead Point is 27½ miles, and for this distance the area of the tidal basin formed by the Cape Fear River is 37 sq. miles, with a rise of tide of 4.5 ft. at the ocean and 2.5 at Wilmington. The mouth of the river is 1.25 miles wide. The estimated volume of flow through it is 160 000 cu. ft. per second for each tide. The average fresh-water discharge into the basin is 14 000 cu. ft. per second; and the influence of the tide is felt ordinarily for 30, and during very low stages of the upper river for 54, miles above Wilmington. The right bank of the estuary is low and marshy half way to the sea; elsewhere the banks are generally high and sandy. The channel between Wilmington and the sea, which had an available depth of 9 ft. in 1870, is being deepened to 18 ft. at mean low water by contraction and dredging. At two points in the river where the natural depth was 14 ft., many stumps of cypress and a few of pine trees were found firmly imbedded in the bottom, erect, and apparently in the position in which they grew.

The entrance to the Cape Fear River is obstructed by a bar occupying a fan-shaped area on both sides of the river mouth, 6 miles long on the coast line and 2 miles wide off the entrance. The main channel across this bar passes close to Smith Island, at Baldhead Point, directly seaward. It is known as Baldhead Channel, and is comparatively permanent in direction. A shoaler channel, known as the Western Channel, passes to the south, close around the point of Oak Island, which forms the west side of the entrance. Inside the mouth a well-defined channel, ¼ mile wide and with depths varying from 25 to 50 ft., extends as far as the Horseshoe Shoals, between Zekes and Smith Islands, a distance of 5 miles. The deep channel there is broken up, and a single well-defined channel is not found until after Federal Point is passed.

"Prior to 1761 the Cape Fear River was reported as allowing vessels of 14 ft. draft to pass over its main bar at low water, and to enter the river by the same route as they follow to-day. In 1761, however, during a violent equinoctial storm of four days' continuance, the wind and sea made a breach, reported at first as 18 ft. deep at high water, and later as not over 2.5 ft. deep at low water, and nearly ½ mile wide, through the sand banks to the Cape Fear River, about 8 miles above

its former bar entrance, at a place called Haulover (between Federal Point and Zekes Island). This breach, cutting off 6 miles of the river's length, gradually increased in importance, so as to form a new mouth for the river, deepening from 6 ft. at low water in 1797 to 10 ft. at low water in 1839, and received the name of 'New Inlet.' The effect of this new mouth upon the river was to diminish the depth of water upon the main bar entrance from 15 ft. in 1797 to 9 ft. in 1839." Up to 1839 "Baldhead Channel was the natural and main entrance to the river. From 1839 to 1872 both the rips (western channel) and New Inlet were the main entrances, and the use of Baldhead was discontinued. Since 1872, and the closure of the New Inlet, Baldhead has again become the main channel, and has been gradually regaining its former depth."*

In 1821 the State of North Carolina began the improvement of the river between Wilmington and the mouth, building some works of contraction, and dredging on the worst shoals. In 1829 the United States assumed charge of the work, and continued operations until 1841. During this period the channel depth below Wilmington was increased from 7.5 to 9.5 ft., the depth on the bar at the entrance. In 1852, with an appropriation of $140 000, the improvement of the mouth was started. A dike was built between Zekes and Smith Islands, to prevent a further widening of New Inlet, and a jetty 300 ft. long was placed at Baldhead Point for its protection. In 1857 a heavy gale wrecked the dike beyond repair with the funds available. The Baldhead Point jetty fulfilled its object until 1871, when it was flanked by the sea.

The next appropriation for this work was made in 1870. At this time the channel depth between Wilmington and the bar was 9 ft. The New Inlet was 4 000 ft. wide, had a least channel depth of 7.5 ft., and was traversed by tidal currents with velocities of 6 miles per hour. This least depth was found at its inner end, showing the preponderance of the flood-current action. Zekes Island had nearly disappeared, and between it and Smith Island was another opening 4 000 ft. wide in which the low-water depths varied from 0 to 20 ft. At the river mouth proper, the Baldhead Channel had decreased in depth to 7 ft., and the Western Channel had a depth of 9.5 ft. In the river channel, between Federal Point and Southport, for $2\frac{1}{4}$ miles at Horseshoe Shoals, the water-way was divided into several small channels, separated by bulkheads having on them depths of 9 ft. and less.

* Captain Bixby, Cape Fear River Improvement.

The total distance by river between Federal Point and the Baldhead Channel bar is 9 miles. The tidal changes at New Inlet occurred from one to two and a half hours before the influence of the change at Baldhead Channel bar could be transmitted through the river channel to the same point. In 158 tides observed in 1880, the average greatest differences in height on the two sides of the New Inlet dam were 1.14 ft. during floods, and 1.53 ft. during ebbs, the greatest being 2.5 ft. for floods and 3.4 ft. for ebbs. The water on the sea side was highest during floods and lowest during ebbs. There resulted, before the dam was built, an interchange of water between the two entrances at each change of tide, with corresponding ill effects in the river channel, as shown by Horseshoe Shoals below Federal Point. The material of the bottom and sides of New Inlet and of the beach was sand. Back of the beach, north of Smith Island, was found marsh mud, with occasional oyster bars. The shoals were composed of a mixture of mud and sand.

It was decided to deepen the channel over the entrance bar by deflecting all of the flow through the one mouth by closing the openings through the beach, assisting the natural scour by dredging; also, to dredge a channel through Horseshoe Shoals. The first step was to build up Zekes Island and to close the opening between it and the beach extending north from Smith Island. This was successfully accomplished in 1873. The new dike then formed the south side of New Inlet. During the same year the beaches were built up several feet by sand catches and plantations of beach grass.

The dike across New Inlet was then started. It crossed the inner end of New Inlet and joined the north end of Zekes Island dike. After much difficulty, on account of the rapid currents and the unstable material of the bottom, this was finished in 1881, completely closing New Inlet. The effects of the work were manifest at once at the river mouth. The currents there were increased, and the flow became more concentrated. Baldhead Channel deepened to 10 ft. in 1874, and to 14 ft. in 1881, while the Western Channel shoaled to 9 ft. in 1874, and to 6½ ft. in 1881. The beach began to form, immediately, across the mouth of New Inlet, until in 1880 the visible accretion in that neighborhood was over 1 500 000 cu. yds.

As soon as New Inlet was completely closed, the river and sea sought to flank it by cutting through the beach north of Smith Island.

An attempt was made to close this "swash" by light pilework, but the tidal currents were too strong and the exposure too great. As these swashes continued to increase in width and depth, a new dike was determined on to connect Zekes Island with the Smith Island marsh, and thus to prevent effectually an injurious deepening of the swashes. For its better protection it was placed ¾ mile back from the beach, near the inner edge of the shoals which there form the river bank. This was finished in 1888; since that date there has been a continual increase of the height and width of the outside beach. After 1870 Baldhead Point began to wear away rapidly. At the same time a hook was formed, leading inward from the point, which held the mouth at its existing width, neutralizing the effect of the erosion. In 1886 a large accretion began to form to the southeast of the point. In 1889 this accretion had reached the point, and it still continues.

In 1874 a suitable hydraulic dredge was bought for work on the bar. She worked there, weather permitting, during 1874–75, 1878–82, and from 1887–92, and removed in all 395 000 cu. yds. of sand from the bar channel and 155 000 cu. yds. from the channel through Horseshoe Shoals. She also worked, from time to time, during four more years, during which no record was kept. Since 1870 dredging has been carried on by contract, as well, in the nine shoals between Wilmington and the mouth, and under the demands of the increasing commerce the protected low-water channel depths have been increased from 12 ft. in 1874 to 16 ft. in 1881, and 18 ft. in 1892. The total amount of material removed up to June 30th, 1892, was 4 778 000 cu. yds. The total cost of the improvement from 1870–1892 has been $2 271 300. The results have been the formation of a channel having least depths at mean low water of 17 ft. at outer bar in Baldhead Channel, and of 16 ft. through Horseshoe Shoals and thence to Wilmington, excepting for 300 ft. at Lilliput Shoals, near Wilmington, where the depth is 15 ft.; while the total commerce of the port has increased from a valuation of $13 500 000 in 1870 to a valuation in 1891 of $23 093 120.

The channels, as formed, will need dredging from time to time, and near Horseshoe Shoals will require the assistance of deflecting works; but the main work, the closing of the false river mouth, seems stable, and by the growth of the outside beach, gains strength year by year. The tidal ranges, at Wilmington and Southport, have remained unchanged throughout the improvement.

Methods and Plant. Zekes Island Dike, 1870–73.—This dike was built of timber cribs, filled with stone, and floored and covered with plank. This method of construction, similar to that in use on the Great Lakes, was adopted to save stone, timber being cheap and stone dear. The work was started from the Smith Island Beach, and, as it progressed, much difficulty was experienced in placing the cribs on account of the high velocities in the narrowing water-way, which induced so much scour that two of the cribs were sunk in water 30 ft. deep.

"From the very commencement of the work at Smith Island, a sand spit, somewhat above high water-mark, followed along on the outer or sea side of the work; its extreme point, however, always keeping a little behind the advanced superstructure. Nor would this sand spit join the work at any point, but followed along in a direction generally parallel to the work, and at a distance from it varying from 40 to 200 ft. This left a water-way along the work in which the tide rose and fell with the tide of the Inlet. It was partly supplied, however, by water, which, at certain points (particularly at the deep holes), leaked through the crib-work. To avert any disaster which might result from this, and to encourage the accumulation of sand on the outer side to protect the timber from worms, several useless and worn-out flats were sunk at the narrow points of this water-way, connecting the work with the sand spit. About 30 000 sand bags were also filled and deposited along both sides of the work. The result was that several ponds were formed along the outer side, which began rapidly to fill up with sand. As the superstructure approached completion, the accumulation of sand became very rapid, not only in the ponds, but along the entire work. Numerous shoals—far beyond the sand spit—also began to show themselves at low water."*

This dike soon was covered completely by sand, and was never seriously damaged by the gales. It was 4 403 ft. long, and cost $60 per running foot. It was finished in 1873.

New Inlet Dike, 1874–81.—To provide a good landing, and to make a shelter for flats and boats used in the work, a crib-work pier, 500 ft. long, was built from Federal Point into New Inlet.

"As the work progressed, a very serious deepening occurred in advance of the line of cribs. By the time 200 lin. ft. had been placed in position, cribs 12 ft. in depth were required where originally there were only 6 ft. of water; and when, in November following, the last crib (completing the 500 ft.) was placed in position, it was sunk in 19 ft. of water, the original depth having been only 6 ft. Many of the cribs settled rapidly after having been put in position, and it was only by great

* Captain Phillips, Rep. of Chf. of Engrs., 1876-I-325-326.

exertions that the cribs could be built upon fast enough to keep them above low water-mark."* The use of cribs was then abandoned.

In 1875 the final closure of New Inlet was begun by laying across the remainder of the Inlet an apron of log mattresses (with the logs at right angles to the axis of the jetty) covered with a layer of brush and loaded with stone. The total length was 4 300 ft., and the width of mattresses varied from 40 to 70 ft. according to the depth, being designed for a top width of rip-rap dike of 16 ft. at ordinary low water, with a slope of 1 on 2 toward the sea, and of 1 on 1 toward the river. The scour in advance of this apron was about 3 ft., and before the dike was built upon it, there was no settlement after the mattresses were placed in position. At the close of the fiscal year 1878, the apron had been raised to the low water-mark, and this partial stoppage developed a difference of head on the two sides which, toward the close of the ebb, became at times as great as 2 ft. There was also a heavy flow across the top of the dike. The inherent weakness of the log mattress apron quickly showed itself. Under the pressure produced by the head, in all the shoaler portions of the work, the water found its way between and under the logs of the mattresses, and gradually settled the foundations, so that there was no portion of the dam (excepting short lengths at the shores) where the base was less than 12 ft. below mean low water. No settlement was observed where the original depth exceeded 14 ft. at mean low water.† The scour along the edges of the foundations, due to flow over the dike, was generally from 8 to 12 ft. Work was continued, as funds became available, by building up the crest with rip-rap until the limit of subsidence had been reached. It was then capped with heavy stone.

In 1881 the dike was practically completed. Its crest is 1 ft. above high water of ordinary spring tides. Above the low water-line it has a capping of undressed granite blocks, weighing from ½ to 4 tons, laid by hand to a smooth face, and having a slope of 1 on 2 on the sea face and a more gentle slope to the rear. The bulk of the dike is composed of one man stone, which took a slope of about 1 on 2 on the sea side and of 1 on 1½ on the land side. The whole dam is 4 752 ft. long, contains about 182 821 cu. yds. of material, and cost complete about $2.75 per cubic yard, or $105 per linear foot.

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* Captain Phillips, Rep. Chf. of Engrs., 1876–I–325, 326.

† Mr. Bacon, Rep. Chf. of Engrs., 1878–I–477.

Dike Across Shoals, 1883–88.—The foundation consisted of a brush mattress apron, part in sections and part continuous, in 5 to 12 ft. of water. This mattress was broad enough to extend beyond the side slopes of the dike, and thus to act as an apron for overflow. It consisted of three layers of brush, of which the lowest was transverse to the axis of the jetty, the next longitudinal, and the third transverse. These were compressed and held by fascine ropes, or binders, 5 to 8 ins. in diameter, strongly bound with spun yarn. The binders were parallel to the axis of the jetty, and were spaced 3½ to 4 ft. apart, in sets of two, one above and one beneath the mattress. The brush was compressed between the binders by a lever to the full strength of the 9 to 18 thread ratlin which tied the upper and lower binders together. The average thickness of the mattresses after compression was 9 ins. They are described as strong and pliable. A portion of the foundation was made of separate mattresses, constructed on a tilting table, 90 x 30 ft., and towed to the site of the work and sunk. Five thousand two hundred feet of the foundation was made of continuous mattress work in two parts, 3 100 and 2 100 ft. long, on a scow 80 x 28 ft., provided with an inclined table 60 x 36 ft. A section having been launched, its binders were spliced to binders on the scow, another section was made, and the scow run from beneath on the line of the axis as before. The sinking of the mattress by stone followed a short distance behind the scow. In the small mattresses made on the tilting table, it was found that by practice an average of 25 ft. in length of fascine binders was made each hour by one man. After the fascines were ready and the binders spliced, the mattresses were made and fully bound at the rate of 7½ sq. yds. for each hour's labor. The cost of labor on mattresses and binders was 3½ cents per square yard of mattress. The cost of labor on the continuous mattresses made on the scow was about 5 cents per square yard. The cost of each style in place was about the same. The cost of the mattresses in place, including materials and plant, was 66.2 cents per square yard, or, allowing 46% for compression, about $2.65 per cubic yard. The cost of the stone in place, including handling, superintendence, etc., was about $2.30 per cubic yard, assuming 1.12 cu. yds. to the gross ton (the stone used for sinking the mattresses was a very light shell stone).

The dike was finished in 1888. The total amount of stone used in construction was 76 000 cu. yds. Its crest is 6 ft. wide and is at the

level of high water of ordinary spring tides. The side slopes are 1 on 1½. The crest and slopes to low water are capped with heavy stone, hand laid to a smooth face, with an average thickness of 9 to 12 ins. The cost of the labor of placing, including wages of foreman, but not superintendence, was 28.5 cents per superficial yard. The average subsidence of the dam due to settling in the mud, compression of mattresses and consolidation of rip-rap was about 2 ft.

Hydraulic Dredge "Woodbury."—This boat was bought and fitted as a dredge in 1874 and repaired in 1880. She is a propeller of 145 tons burden, and is provided with a 9-in. centrifugal pump, driven by a double oscillating engine, with 10-in. cylinders, and has two suction pipes of boiler iron with an internal diameter of 6¾ ins. Her average day's work was 515 cu. yds. Her bin capacity was 45 cu. yds., and the bins were frequently filled in 25 minutes. She could dredge in 6 to 14 ft. of water. She proved exceptionally efficient for ocean-bar work, where wave action is heavy, and was used in Baldhead Channel. When driven from there by storms, she dredged in the Horseshoe Shoals channels. The cost of her dredging, including repairs and an allowance for deterioration, varied between 11.75 and 14.8 cents per cubic yard. The contract price for similar dredging in the smooth water of the river during the period under discussion varied from 12 to 16.7 cents per cubic yard.

Remarks.—The history of this work may be summarized as follows: Prior to 1761 the river had but one entrance, the channel was straight and permanent, with a depth of 14 ft. Its direction was that taken by the ebb currents from the river. During a heavy gale accompanied by an exceptional tide, the sea swept across the unprotected sand barrier 9 miles above the bar, and the times of the change of tides on the two sides of the barrier being an hour apart, the difference of head developed tidal currents which scoured out the sand and opened a new mouth. The power of the ebb currents being divided, the original channel shoaled, and three channels were developed of which two, the New Inlet and the Western, had the characteristics of flood channels, all with less available depth. The false mouth was closed, and the single channel with its greater depth was re-established.

From the history of the first dike is seen the inadvisability of closing a channel having rapid currents over an unstable bottom by a dike built from one side, to full height, with large unyielding

elements (cribs), causing heavy scour in advance, under and between the elementary parts. The rapid advance of the sand spit along with and separated from the dike, and its extension to the dike by the use of spurs, and the tightening of the dike with sand bags, are characteristic.

In the New Inlet dike is seen the advantage of the continuous low apron laid in advance, an advantage which is partly lost by the stiffness and permeability of the log mattress, which, unless very wide, and on a bottom perfectly level on the line of the logs, affords, under pressure, a water-way under and between each of its elements, with consequent scour and increase of depth. (This same action will be found later in the history of the St. Johns improvement.) There is also seen the scour produced by the overflow before the dike had reached its full height, and the final closure of the water-way by simple rip-rap, which, following up the scour, soon reached the limit of settlement. A more detailed history would show also that it was impossible to hold light rock in the dike above the level of mean low water under the wave action of even so sheltered a location without a capping of heavy blocks, laid with smooth and gentle slopes, and with the joints carefully chinked.

In the third dike is found a better form of mattress, more pliable, and with no continuous water-ways, and an apron at the side to protect from scour. Of this foundation Mr. Bacon, the assistant engineer in local charge, says:

"Notwithstanding the pliability of the mattresses, and the fact that the bottom fascine binders are longitudinal with the dam, the water found its way under the mattresses and caused a subsidence in many places where it could be definitely observed at low water. * * * * The experience of many years has convinced me that the foundation placed on sand or mud most secure from undermining by water is of small stone rip-rip. In a soft foundation of comparative stiffness, rip-rap will settle more or less and finally secure the characteristics of an unified platform, and will support the weight required of it with perfect stability. In a formation of sand, the limit of subsidence is soon reached, and the water ceases to pass under the stones. Whenever the mattresses are not covered with sand or mud and are below half tide, they are thoroughly eaten by the teredo worms. All kinds and sizes of wood are thoroughly perforated, down to $\frac{3}{16}$ in. in diameter." *

The enormous extent of the coast sand movement is seen from the

* Rep. Chf. of Engrs., 1885-II-1092.

fill in the beach outside New Inlet, and the tendency to form a continuous coast line from the rapid closure of the inlets when the currents through them were stopped.

This successful work was in charge of Colonel W. P. Craighill from 1870 until 1884, of Captain W. H. Bixby from 1884 until 1891, and since that date, of Major W. S. Stanton. The assistants in local charge were Captain C. B. Philips, 1872 until 1876; Mr. Henry Bacon, 1876 until his death in 1891; and, since that date, of Mr. E. D. Thompson.

Charleston Harbor Entrance.

The City of Charleston lies on the point of land formed by the junction of the Cooper and Ashley Rivers. The lower reaches of these rivers, with the irregular water-way between Charleston and the opening in the coast line between Sullivans and Morris Islands, form the harbor, with a tidal basin of more than 15 sq. miles area. There are two tides daily with a mean range of 5.1 ft. An extreme range of 10.3 ft. has been observed. The mean duration of rise is 6 hours 15 minutes, and of fall 6 hours 9 minutes. The average discharge during ebbs through the throat of the harbor, $1\frac{5}{8}$ miles wide, between Sullivans and Morris Islands, has been estimated to be 3 655 000 000 cu. ft., of which about 76 000 000 cu. ft. is supplied by land drainage. The capacity and safety of the harbor is shown by the map (Plate III).

The entrance, or throat, of the harbor lies at the head of a shallow re-entering angle of the coast. The coast line, rectified between a point on Long Island 8 miles northeast of the entrance, and the extremity of Morris Island, $3\frac{1}{2}$ miles to the south, would be $2\frac{1}{2}$ miles off Fort Moultrie at the entrance, and $\frac{3}{8}$ mile to 3 miles inside the 18-ft. contour of the fore shore. The shoals known as the Charleston Bar, formed by the influence of the harbor on the coast drift, begin at a point about 1 mile northeast of the entrance, off Sullivans Island, and separated from it by Beach Channel, $\frac{1}{4}$ mile wide, and extend from there down the coast for 7 miles. The general depth on the crest of the shoals varies from 3 to 9 ft., excepting in the channels. The 18-ft. contour of the outer slope is about 1 mile seaward from this crest, and the average width of the bar between the 18-ft. contours is $1\frac{3}{4}$ miles. Charts extending back to 1780 show that the bar has varied comparatively but little in extent, direction, or in distance from the mouth of the harbor. The main central body of the bar is 5 miles long.

The surface of the bar shows materials closely resembling those found on the seashore in that section of the country, being shells, fragments of shells and silicious sand. Borings in the northern end of the bar showed some layers or lumps of mud, or of sand and shells mixed with mud. "So far as we can now ascertain, there appear never to have been less than four nor more than six ship channels across the bar at any one time. The greatest depth of water has sometimes been found in one channel and sometimes in another, being rarely less than 12 ft. or more than $13\frac{1}{2}$ ft. at mean low tide. These channels, whether four or more, have always existed in two groups or clusters, one in the northern and one in the southern curved portions of the bar, and there has always been a deep and broad anchorage inside the straight reach of the bar abreast of Morris Island. * * * * At the extremities of this outer harbor or basin, several miles apart, are found the two groups of channels already mentioned, the most northerly group being directly in front of the gorge of the harbor."

"The bar is essentially a drift and wave bar * * * * The peculiar location of the bar, largely to the southward of the gorge of the harbor, and the conditions under which a very large proportion of the ebb flow is diverted from its most direct path and forced to skirt the main coast for several miles before it can find a passage to the sea, indicates the controlling power of these (northeast) storms."*

All the channels across the bar have the characteristics of ebb channels excepting Beach Channel, now closed, and a shallow channel close along the Morris Island shore. The reports of the chief signal officer quoted earlier show the predominance of the northeast gales. The mud lumps on the bar are easily accounted for by the erosion of the beach to and through the underlying marsh mud. Observations made in 1878 showed ebb velocities of $1\frac{1}{2}$ to $1\frac{3}{4}$ miles per hour in the north channel in depths of $8\frac{1}{2}$ to 9 ft., and in 22 ft. of water on the outer slope of the bar of 1 mile per hour at the surface and $\frac{1}{2}$ mile per hour at the bottom. "Other observations made at different points of the harbor simultaneously showed that the flood tide made its appearance first in the Beach Channel and afterward in each of the channels to the south of it in succession, the last of the ebb passing through what is called the Main Ship Channel to the Pumpkin Hill and South channels."†

The first appropriation by the United States for the improvement of the harbor was made in 1852. It was applied to deepening Beach

* Rep. Chf. of Engrs., 1873-I-555.

† Rep. Chf. of Engrs., 1878-I-546.

Channel by dredging, but without substantial results. A short jetty was also built near Fort Moultrie on Sullivans Island, to protect the beach from erosion. Other appropriations were made between 1871 and 1876. These were used in removing a portion of the Bowman Jetty on Sullivans Island, for the purpose of straightening Beach Channel, in dredging in Beach Channel and in the removal of wrecks. In 1874 and 1875 the authorities of the City of Charleston attempted to deepen the Pumpkin Hill Channel by dredging. None of the dredging operations afforded permanent relief.

In 1878 a project was adopted for deepening the channel over the bar to 21 ft. at mean low water by means of jetties, in accordance with the plans of the late General Gillmore. It was proposed to construct two jetties, one springing from Morris Island and the other from Sullivans Island, curving toward each other in such a manner that their outer ends on the crest of the bar should be ½ to ⅝ of a mile apart. The outer ends of the jetties were to rest on the shoals to the north and south of the middle channel of the north group of three channels, with the line of the proposed jetty channel nearly in the prolongation of the axis of deep-water flow through the gorge of the harbor between Cummings Point and Fort Moultrie. The jetties were to be submerged, especially at their inner ends, but the total length and height were to be regulated by the results obtained.

Work on the north jetty was begun in December, 1878. A foundation course of log mattresses, varying in width from 40 to 118 ft., ballasted with stone, was laid to the crest of the bar, a distance of 14 330 ft., with a total height of from 2½ to 4 ft. Beginning 5 300 ft. from the shore end, for 5 800 ft. seaward, there is a second course of mattresses and stone. The width of the mattresses varies from 55 to 90 ft., according to the depth. Up to June 30th, 1892, 175 155 sq. yds. of mattresses and 159 369 cu. yds. of stone (at 2 600 lbs. to the cubic yard) had been used in the construction of the jetty.

The south jetty was started in 1880. In 1887 the foundation course of stone-ballasted mattresses had reached a point 16 440 ft. from the shore end on Morris Island. The width of the foundation varies from 40 to 130 ft. In the deep water at and near the crossing of the existing main ship channel, the width of the bottom course was increased for 4 256 ft. by a mattress apron to from 135 to 206 ft. A second course of mattresses was laid in the deepest portions for 10 586 ft., and a

third course for 1 206 ft. For a portion of the distance short spurs were made by having each third mattress of the foundation course longer than the other two. Beyond the main ship channel fifteen sets of spurs, 100 ft. long and 50 ft. wide, were laid. Up to June 30th, 1892, 306 585 sq. yds. of mattresses and 212 301 cu. yds. of rock (at 2 600 lbs. per cubic yard) had been used in the jetty.

The width between the sea ends of the jetties, center to center, is now 2 900 ft. The heights and lengths on June 30th, 1892, can be seen on the profiles shown on Plate IV. Above the mattress work the stone is ridged along the jetty axis with a crest about 10 ft. wide. Under wave action the crest is lowered, and the stone assumes stable side slopes. When desirable, the crest is raised with more stone. Work on the jetties continues. Until the sailing gap, which has been left at the point where the main ship channel crosses the south jetty, has been more nearly filled, the extent to which the tidal flow must be restricted by the jetties in order to form and maintain the desired depth of 21 ft. at mean low water in the jetty channel is more or less conjectural. Too many conditions must be considered to permit this to be calculated. This gap cannot be closed until the jetty channel has become the main ship channel, and the usefulness of the old ship channel has ceased.

The cost of the mattresses in place was from 49 to 72 cents per square yard; of the ballast stone in place, from \$3.09 to \$3.60 per cubic yard; of the one man stone in the superstructure, \$1.90 per short ton (\$2.47 per cubic yard); and of the heavy stone, in ½ to 5-ton blocks, from \$1.90 to \$2.15 per short ton (\$2.47 to \$2.80 per cubic yard), not counting cost of inspection and superintendence. The total cost of the work, including the protection of Morris and Sullivans Islands and dredging, from 1878 to June 30th, 1892, is about \$2 190 000. The cost of the jetties to the same date has been \$70.46 per lineal foot.

In 1884 and 1885, 85 549 cu. yds., and from 1890 to 1892, 205 421 cu. yds., of material were removed from the jetty channel by dredging. The cost of the dredging by contract was in 1885 30 cents per cubic yard, and in 1890 and 1891 17¼ cents per cubic yard. Dredging carried on with United States plant cost in 1892 11½ cents per cubic yard.

The results of the work on the jetty channel have been (1) a general movement of the crest of the bar there seaward, between 1882 and 1892, of 3 600 ft. in the north third, and of 5 600 ft.

on the middle third, between the jetties; (2) an increase of least depth of 1½ ft. in the first area, or 3½ in the second, and of ¾ ft. in the south third; (3) an increase of the outer slope of the bar from 1 on 300 to 1 on 200 in the first area, and from 1 on 200 to 1 on 150 in the middle area; and (4) a general deepening of the entire area between the jetties. The advance of the outer slope of the bar, as shown by the 18-ft. contour, was about 400 ft.

More recent surveys show a least mean low-water depth of 15 ft. (in February, 1893) on the sailing range; a further increase of the general depth between the jetties; and a further movement seaward of the crest of the bar between the jetties. "The water between the jetties at the strength of the ebb tide is about 7 or 8 ins. higher than it is on the outside at the same distance from shore. This is the maximum difference, and is found, say, about 1 000 ft. outside of the present inner end of the high-water portion of the south jetty."* Recent current measurements show a corresponding increase in the strength of the ebb currents in the jetty channel.

Materials and Methods.—The last advertisement for proposals, calling for bids to furnish mattress work, stone and dredging, describes the mattresses to be used as follows:

"Rafts of round logs will be prepared. The logs must not be less than 12 ins. average diameter, and no log shall be less than 9 ins. in diameter at the small end. They must be placed in close contact, side by side, and firmly held by transverse pole binders, spiked to them with spikes not less than 15 ins. long. A layer of live wood brush, 1 ft. thick when closely packed, will be placed upon the logs and secured by poles lashed to the binders of the raft. The binders will be small logs or poles not less than 6 ins. in diameter at the small end. They will be placed not more than 8 ft. apart, and those on the outside will be close to the end of the logs."

The mattresses are to be 100 ft. wide. These, when used, are to be covered with 3 ft. of stone in pieces not less than 10 lbs., nor more than 250 lbs., in weight. They will be used, should a further extension of the jetty be decided upon. On these will be piled stone, in pieces from 1 to 7 tons in weight, along the axis of the jetty to the level of high water, with crest from 5 to 10 ft. wide, and such side slopes as the stone will take.

All stone is required to be hard and compact, and, where exposed to wave action, it must be hard and heavy granite. It is to be paid for in tons of 2 000 lbs., as determined by railroad weight, or by the displacement of lighters, provided with a 3-in. well within 12 ft. of each

* Captain Abbot, letter of March 14th, 1893.

end, to measure the draft, as will be described later. The displacement of the lighters under the various loads will be determined by piling on known weights. The prices for stone under these specifications are $3.20 per ton for shore work, and from $2.25 to $2.35 for the remainder, according to the location of the work; for mattresses, the price bid is $1.25 per square yard, and for dredging, 28 cents per cubic yard. The matt: esses, as described above, are practically the same as have been used throughout the work.

Since 1889 a large proportion of the stone used in the work has been taken from the Government quarry at Edgefield, 144 miles from Charleston. It is brought by rail to Charleston and lightered to the jetties. The work was done by hired labor until October, 1893; since that date, entirely by contract. Excepting the railroad equipment, about one-third of the plant used is the property of the United States, which is now hired by the contractor. The rock is a heavy compact granite, and is taken out in blocks weighing from 20 lbs. to 7 tons, as much as possible in the large sizes. It is placed in the jetty by the aid of a derrick-scow, which carries a Lidgerwood hoisting engine, capable of lifting 8 000 lbs. on a running line, and operating a turn-table derrick of 10 tons capacity. No special difficulty was found in handling the rock in the swells prevailing, excepting that the elasticity of the line was insufficient to enable the cog-gearing of the turn-table as first used to withstand the shocks incident to lifting the heavy weights in a seaway. It had to be replaced by another device. The saving to the United States in 1892 by the use of its own quarry and plant amounted to between 40 and 50 cents a ton, without any allowance for cost and deterioration of plant. At present the work is all done by contract, pursuant to the provisions of the River and Harbor Act of July, 1892, the Government plant being rented to the contractor for $3 375 per month.

Dredge.—In 1891 a hydraulic dredge, suitable for work on the bar, was built by the United States. The dredge is 122.5 ft. long, 30 ft. beam, and has 12 ft. depth of hold. She is furnished with a steeple, compound, Sullivan, propelling engine, with cylinders 17 and 32 ins. in diameter, and 22-in. stroke. She has one propeller, 7 ft. in diameter, and on her trial trip, without a load, had an average speed of 10 miles per hour. Her pumping machinery is of the B. C. Howell pattern, and consists of a 230 H. P. compound engine, coupled direct by a shaft to a centrifugal pump with a 14½-in. suction, and a 15-in. discharge pipe. Her maximum bin capacity is about 270 cu. yds. Her crew is 16 men.

Experience had shown that on a sand and drift bar, in a seaway, such as is found between the jetties, dredging can be carried on economically only by a powerful, self-propelling, hydraulic, hopper dredge, having sufficient speed and bin capacity.

It is interesting to note that hydraulic dredging with a centrifugal pump was invented at Charleston in 1855 by Mr. Lebby. The late General Cullum was at that time the engineer in charge of the harbor work. He was much impressed by the capabilities of the method, and with his encouragement a powerful propeller was fitted with a bin and a pump 6 ft. in diameter, having a 19-in. suction. She was used in the Sullivans Island channel in 1857 with great success, the average day's work being 328 cu. yds. and the maximum 1 005 cu. yds. Although manifestly the method most suitable for dredging in a rough seaway, it seems to have fallen into disuse during the Civil War. It was revived in 1871, when the steamer *Henry Burden* was fitted for hydraulic dredging upon plans devised by Captain (now Major) William Ludlow, Corps of Engineers, under the orders of the late General Gillmore, substantially in the manner still in use for hydraulic dredging from a steamer under headway. A full description of her, as she was fitted in 1875, is to be found in the Annual Report of the Chief of Engineers for 1875. She did efficient service in Charleston and several of the other South Atlantic Coast harbors.

Remarks.—General Gillmore's project for the improvement of Charleston Harbor has been criticized widely, both favorably and unfavorably, by members of the engineering profession. A cause for a portion of the unfavorable criticism may be found in the apparent delay in the attainment of marked results. This delay is, however, accounted for fully when the scope of the project is understood and considered along with the meager and intermittent supply of money for carrying it into execution. The estimated cost of the completed work, as revised by Captain Abbot, the engineer in charge in 1889, is $4 380 000 if the jetties are built to mean low water only, and $5 300 000 if brought throughout to 3 ft. above mean low water. Up to June 30th, 1892, the appropriations averaged $157 000 per annum, made in nine appropriations, an annual allowance of about 3½% of the total cost.

The reasons which guided General Gillmore in the formation of the project are to be found in Part I, Report of the Chief of Engineers, for 1878. His recommendation to keep the inner ends of the jetties

submerged is for the two-fold purpose of admitting the flood tide more freely and of attempting to prevent any considerable seaward movement of the main body of the bar. The growth seaward of the shore on the north side of a high north jetty at Charleston was to be anticipated from the known sand movement of the coast and from the observed effects at other harbors. It was General Gillmore's belief that with the inner end of the north jetty low, the moving sand would cross the jetty, be carried to sea by the strong ebb current from the harbor, and then be moved to the south, after passing the ends of the jetties, by the same storm movement which brought it in. Up to the present time absence of growth of the shoal north of the north jetty, and the continuous, though slow, deepening of the jetty channel, apparently show the correctness of this hypothesis. It remains to be seen whether the ebb currents can be sufficiently controlled by the submerged jetties to produce head enough to create the velocities necessary for scouring out the deeper channel.

Though progress has not been rapid, the final deepening of the jetty channel cannot be doubted. Should a modification of the jetty heights be necessary, it can be made easily. The present work of ridging the stone above low-water level is only temporary in character, and a lowering under wave action is expected. The crest can be raised and made permanent later, or left low, as may prove most expedient. In the meantime there is no increase in cost, and with each month valuable information is gained from the observed effects.

The log mattresses, as used in Charleston Harbor, have proved satisfactory to the engineer in charge for foundation work. For a rough site, he condemns them.

"Where ridged stone has been used in the work done under previous appropriations, it is impracticable to use mattresses (log) unless the ridge be first leveled off. * * * * Mattresses which sunk in perfectly good shape on the rough stone piles near the former Drunken Dick Gap, broke to pieces as they received the additional loading of stone, and some of the logs stood up 10 or 15 ft. above the general level. It was found to be very hard to get stone to stay on them at all, the mattress breaking in the middle, forming a sort of sloping roof to the work beneath, and the rip-rap sliding off into deep water on either side."*

The reported settlement in the low jetties was generally from 1 to 2 ft., excepting in Beach Channel where it was $3\frac{1}{2}$ ft. No settlement has been reported since the jetties crossed the natural channels. When

* Captain Abbot, Rep. Chf. of Engrs., 1889-II-1154.

the north jetty was being extended in 1879, a shoal, known as Drunken Dick Shoal, was found having on it too little water to float the mattresses. A gap was left, and the jetty started beyond the shoal. The shoal up to that time had varied but little in position. It was thought that, should it remain permanent, it would act as part of the jetty. If not, the gap could be filled. By 1881 the shoal had scoured in places to a depth of 11 ft., and the jetty was extended across its site. This illustrates a fact not always appreciated by engineers not familiar with work in such localities—that shoals of any erodible material are permanent only so long as the surrounding conditions remain unchanged. It is not safe to depend on them for a part of a system in connection with new constructions. No matter how permanent in position and extent they may have seemed, the sand bars along our southern coast are really in a state of unstable equilibrium, and are subject to radical change with a change of conditions.

The Charleston jettywork was started under General Gillmore, and he remained in charge until his death in 1888. Since that date Captain F. V. Abbot has been in charge. The assistant engineers have been Captain J. C. Post, Captain B. D. Greene, Lieutenant T. N. Bailey and Lieutenant F. V. Abbot, of the Corps of Engineers, and under Captain Abbot, Mr. James P. Allen, C. E.

Savannah Harbor.

The harbor of Savannah is formed by the lower Savannah River, an estuary opening into the sea at Tybee Roads, which above Savannah receives the discharge from the upper river. The distances of points on the estuary from the Whistling Buoy off the entrance, together with the tidal regimen of the estuary, are given in the following table:

	Distances, miles.	Corrected establishment.	Mean luni-tidal interval of low water.	Mean duration of—		Height above m. l. water at Fort Pulaski.		Change of current after—	
				Fall.	Rise.	H. W.	L. W.	H. W.	L. W.
		h. m.	h. m.	h. m.	h. m.	ft.	ft.	h. m.	h. m.
Whistling Buoy	0								
Tybee Island	7	7 15½	13 26	6 10½	6 14½	6.9	0.02	....	...
Fort Pulaski	9.5	7 15½	13 54	6 38½	5 46½	6.97	....	0 58	0 53
Barge Office, Savannah	24	8 14½	15 36	7 21½	5 03½	7.41	1.34	....	....
Cross Tides (Upper Grange)	28	8 37	16 29	7 52	4 33	7.48	3.02	0 13	1 25

Thirteen miles above Savannah the estuary is divided into three channels, which at Cross Tides, 4 miles above Savannah, unite into two, known as "Front" and "Back" Rivers. Front River skirts the city and then unites again with Back River. From this point to the sea the banks are low and marshy, and low marsh islands divide the flow into different channels. The bottom is of soft mud, or of mud and sand. Seven miles above Fort Pulaski, St. Augustine Creek opens a side communication with the sea from the south channel, through Tybee and Wilmington Rivers, as does also Lazaretto Creek, west of Tybee Island, near the mouth.

The portion of the estuary to be considered in the problem of the improvement of Savannah Harbor lies between Cross Tides and the sea. The problem is complicated by the discharge of the upper river, which may vary from 4 500 cu. ft. per second at low water to 400 000 cu. ft. per second during extreme floods, and which in floods carries large quantities of sediment; by the division of the thalweg into several channels, having varying velocities of tidal propagation and current; by the flow to and from St. Augustine and Lazaretto Creeks; and, finally, at the mouth, by the currents to and from the small estuaries opening to the sea close to the Savannah River, between Tybee Island on the south and Hilton Head Island on the north.

Prior to 1763, the depth on Tybee Knoll was 15 ft., and a good, clear channel was reported as far as Savannah. Between 1760 and 1822 much complaint was made of the shoaling of the river, caused by deposits of ballast and by drift and sediment from the upper river. As much as $100 000 was collected by a tax on shipping, which, under the State authority, was to be applied to clearing away wrecks, etc. In 1826 the United States made the first appropriation of $50 000 for the improvement of the harbor, to be expended by the Treasury Department. In 1830 vessels drawing 13 to 14 ft. of water were able to go to sea with favorable winds and tides, the depth just below Savannah having been 6½ ft. in 1816, and 7 to 7½ ft. in 1830. Other work was done by the United States under the direction of officers of the Corps of Topographical Engineers, and, at the outbreak of the Civil War, vessels drawing 17½ ft. were able to come to the city wharves by taking advantage of the tide. The channel was obstructed again during the Civil War by wrecks, cribs and torpedoes. These caused the formation of shoals, which decreased the high-water channel depth from 17½ ft. to

13½ ft. After the close of the war some of the wrecks were removed by the United States, and other work was done by the city authorities. In 1872 the United States Engineer Department resumed charge of the work.

The earlier works had included dredging, the removal of wrecks and the deepening of the channel by dikes and deflecting works. Several unsuccessful attempts were made to close the opening into Back River at Cross Tides, and the channel north of Fig Island. Finally, in 1857, the Fig Island dam was successfully built, and also a deflecting dike at King Island, above the city. None of this work gave permanent relief.

In 1873 General Gillmore submitted a project for the formation of a channel, 23 ft. deep at high water, from Savannah to the sea. This was to be accomplished by building a dam at Cross Tides, by widening the water-way opposite the city to 575 ft., and by dredging in the lower reaches, aided by such deflecting works as might prove needful. Work was carried on under this project as money became available. In 1881 the Cross Tides dam was completed, with very marked beneficial effects on Front River Channel. The project was successively modified and enlarged in 1879 and 1882, and work under it continued until 1890, when a revised and enlarged project was submitted by Captain Carter, based on a careful survey of the lower river.

This survey showed the general condition of flow to be about as follows (see Plate VI). Savannah River proper is entered by a flood volume of about 1 850 000 000 cu. ft., of which one-fourth enters the south channel. Below the mouth of the north channel the total flow on the north and south, past Oyster Bed, is 2 100 000 000 cu. ft., of which 300 000 000 cu. ft. enter Wrights River, and 1 390 000 000 cu. ft. the north channel.

Above St. Augustine Creek, the south channel flow, which had diminished to about 0.4 of its original volume, is increased by the flood inflow from the creek to 414 000 000 cu. ft. Above Elba Island the two streams from the north and south channels join and have a united volume of 1 100 000 000 cu. ft. After filling the tidal basin below Hutchinson Island, about .78 of the remainder passes up Back River and .22 up Front River. At Cross Tides the flow up Front River is increased from 114 000 000 to 140 000 000 cu. ft. by overflow from Back River.

On the ebb the flow through Front River above Cross Tides is 856 000 000 cu. ft.; 300 000 000 cu. ft. of this passes the dam into Back River, which just above Cross Tides has a flood volume of 165 000 000 cu. ft. Arrived at the head of Elba Island, the flow is divided nearly equally between the north and south channels. From the south channel about 350 000 000 cu. ft. passes out through St. Augustine Creek, and a smaller portion through Lazaretto Creek; so that, where the channels join, the ebb flow from the south channel is about one-half that from the north. The total ebb flow from the river is 2 570 000 000 cu. ft. Near the end of the north channel the flow from the river to the south of Oyster Bed is 1 450 000 000 cu. ft., about double that to the north, which has been augmented also by the ebb from Wrights River.

Captain Carter concludes that a mean ebb velocity of about 2 ft. per second is required, to secure permanence to the channel. He proposes so to adjust the cross-section of the river as to give a navigable channel through North Channel and Front River from the sea to Savannah, which shall have a depth at mean high water of 26 ft., and shall permit a free access to floods and, as far as practicable, a uniform velocity of 2 ft. per second for ebbs. In Front River the adopted width varies from 500 ft. at Cross Tides to 600 ft. at Kinsey Point, and 700 to 750 ft. at mouth of Wrecks Channel. In the North Channel the widths will vary from 1 200 ft. at the head of Elba Island to 1 870 ft. at Long Island crossing.

The principal factors of the proposed improvement are:

First.—The enlargement of Drakie Cut.

Second.—The entire or partial removal of King Island.

Third.—The construction of a deflecting jetty from Argyle Island.

Fourth.—The partial removal of Marsh Island and the closing of the channel north of it.

Fifth.—The construction of a training wall from Marsh Island to Kinsey Point and the enlargement of the river near there.

Sixth.—The construction of a training wall at Garden Bank.

Seventh.—Spur jetties or bank protection in the Wrecks Channel, and a deflecting jetty at Mackay Point.

Eighth.—The removal of a portion of Dam No. 15.

Ninth.—The closing of Duck Puddle.

Tenth.—The construction of shore protection and of training walls

between the wing dams in North Channel, from the upper flats to the Oyster Bed.

Eleventh.—The construction of training walls extending eastward from Cockspur Island and the Oyster Bed.

Twelfth.—Dredging is provided for between the Cross Tides and Tybee Roads.

The estimated cost of this improvement is $3 500 000, providing funds are regularly and adequately supplied.

Up to 1890, when the present 26-ft. project was adopted, the following sums had been spent on this improvement:

Prior to 1826, about $100 000, by the State;

1826–60, $374 000, by the United States;

1867–71, $157 000, by the City of Savannah;

1874, $193 000 (removal of war obstructions);

1872–90, $1 212 000.

Under the existing project there had been expended to June 30th, 1892, $346 000. The work since 1872 has increased the available high-water depth from 14.5 ft. to from 21 to 22 ft., and "the increase on the value of exports since the year 1873, when the work was begun, is proportional to the cube of the increase in the depth of the water during the same period."* The positions and lengths of the various works are shown on Plate VI.

Methods; Fig Island and Cross Tides Dam.—The necessity for increasing the depth of water in Front River by concentrating into one channel all or a portion of the water escaping from it at Cross Tides, and between Fig and Hutchinson Islands, was recognized as early as the close of the last century. Accordingly, efforts were made from time to time to close these channels by sinking wrecks in the waterway, and by building dams of crib-work, piling and of ballast stone, tightened with oyster shells, gravel and clay. The soft mud bottom, the erodible material of the shores at the abutments and the alternating flow in the two directions made these works particularly difficult to construct and maintain, and they were undermined and wrecked either during construction or soon after completion. It was not until the third or fourth attempt that the Fig Island Channel was finally closed, in 1853–54.

The Cross Tides Dike proved even more unmanageable. In 1876 it gave rise to an important decision by the United States Supreme Court

* Report of Captain Carter.

on the authority of the United States over her inland water-ways. Construction of the closing dam, which was started in 1876, was suspended by a temporary injunction, granted by the Supreme Court on the petition of the State of South Carolina, which objected to the interference that the dam would cause with the navigation of Back River, which formed the boundary between the States. The injunction was removed after the case had been heard, the Court deciding that the authority of the United States in the matter was absolute. The dam was to consist of two rows of piling braced together, the flow to be regulated by shutters in the openings in the upper row. Soon after the work was renewed in 1877, the partly finished structure was injured by a freshet, and abandoned.

In 1879 a new dam was started near the site. This was finished in 1881. Its foundation consisted of a mattress of brush and cane, ballasted with stone. It was brought to about the level of mean low water with rip-rap stone, except near the Argyle Island end, where, for 100 ft., there was a low-water depth over it of 6 to 8 ft. In 1882 the crest was raised to 3 feet above low water with brush mattresses and rip-rap. The increased pressure on the dam induced undermining and settlement, and in 1885 it was raised to mean high-water level again, with brush fascines and stone, and, the stability of the work having been threatened by the scouring of a hole 40 ft. deep by the overflow at the east end of the dam, an apron of log mattresses, 40 to 70 ft. wide, was placed along the base. As the log mattresses settled, the gaps made were filled with brush fascines and stone. Repairs were continued as needed until 1888, when the dam attained a stable condition, with a crest about 1.5 ft. above low water. The contract price of the dam, as constructed in 1879–80, was $9.47 per linear foot of apron, of an average width of 25½ ft., and $2.41 per cubic yard of rip-rap superstructure.

The effect of the dam on Front River was immediate. The average mean bottom velocity was raised from 1.75 to 2.37 ft. per second, and between 1879 and 1889 the cross-sectional areas and the mean depth increased 20 per cent. The difference of level on the two sides of the dam amounted to about 3 ft. This heightening of the low-water plane has caused a reduction (estimated to amount to 75 000 000 cu. ft.) in the tidal prism of Front River. In the new project this is to be made up by the enlargement of other portions of Front River.

The other dikes and jetties are shown on the map (see Plate VI). Almost all "are built of log mattresses of an average thickness of 15 ins. The mats are covered with from 4 to 9 ins. of brush and loaded with from 5 to 9 ins. of stone, the top course receiving about 13 ins. In profile the shore ends of the dams are at high water-line, or at the height of the adjacent shores. The crest then slopes down to about 5 ft. above mean low water, which height is maintained to within about 200 ft. of the outer end of the dam; the crest then falls gradually to the outer end, where a tow, or wider lower mat, is placed. Repairs, when needed, have in general been made by filling the holes with brush fascines loaded with rip-rap stone."*

The spur dikes for bank protection at Elba and Jones Islands are built of piles and brush as described below. The Oyster Bed training wall consists of a mattress foundation and a superstructure of rip-rap, having its crest at mean low-water level.

The latest specifications for the Savannah Harbor work describe three varieties of mattresses, either one of which may be used. The first is similar to that used in Charleston Harbor. The second is a brush fascine mattress, similar to those of the St. Johns jetties. The third is like the second, excepting that the top layer of fascines is omitted.

The training walls and spur dikes are to be built as follows: Two rows of piles, 6 to 8 ft. apart, will be driven, the piles of each row being 8 ft. apart between centers. They will be driven on straight lines, vertically, 16 ft. into the bed of the river and will be cut off 10 ft. above mean low-water level. Waling strips of 6 x 10-in. timber will be bolted to each pile, on the outer side of each row, 1 ft. above mean low water. At each second bent the rows will be tied together and braced with 6 x 10-in. timbers, drift-bolted to the piles and to the waling strips. The space between the piles will be filled up to half-tide level with brush fascines, weighted with 250 to 500 lbs. of stone to the running foot. At the ends of the spur dikes the banks, where necessary, will be sloped back to an easy grade and protected with brush fascines, ballasted with stone, or staked to the bank. On the channel side of training walls, close to the piling, will be placed mattresses, 15 to 20 ft. wide. The ends of the spurs and such other points as may require it will be protected by clusters of piles. The spurs and training walls will be braced at intervals by a 6 x 10-in. timber, abutting against a cluster of two piles 12 ft. in rear.

*Captain Carter, Rep. Chf. of Engrs., 1888-II-1021.

Since the work began, the prices for materials in place have been as follows: Log and brush mattresses, 43 to 85 cents per square yard; brush fascines, $1.40 per cubic yard; stone, $2.90 to $3.19 per cubic yard; pile-work, $1.50 per cubic foot; oyster shells, $1.29 per cubic yard.

Between 1872 and June 30th, 1892, 2 675 671 cu. yds. of material have been removed from the channel by dredging, at a cost varying from 15 to 19 cents per cubic yard. This, as well as almost all of the dike and jetty work, was done by contract.

Remarks.—The greater part of the increase of channel depth has been due to a judicious use of wing dams and training walls. The instability of the river-bed, and the accuracy with which the cross-sections must be regulated, is shown by the following incident, related by Captain Carter. In 1885 two spurs were built from opposite banks of the river at a shoal on which the original depth was 12 ft. Within three months after completion, a 15-ft. channel, 300 ft. wide, had been formed between them. Shortly after, the crests of the spurs were lowered to mean low-water level by a cyclone. Shoaling immediately began, and in a short time the original depth of 12 ft. was restored. In 1886 the dams were repaired. The additional depth was again scoured out and has been maintained since.

The cost of this improvement has been increased by the late change of project, which will necessitate the removal of some portions of works now in place. As this change has been necessitated by the demands of a commerce which has grown to its present proportions as a result of the improvement effected by the works, it may be granted that they have paid for themselves in full measure.

A history of this improvement would be incomplete without a notice of the careful survey of the river made in 1889–1890 by Mr. E. A. Gieseler, Assistant Engineer, under the direction of Captain Carter. In the report of this survey* the involved problem presented by the gauging of a tidal stream, flowing through several channels and receiving a varying fresh-water discharge, has been carefully and elaborately worked out. The methods followed are described in detail, and may well serve as a model for future work of that character.

From 1872–78 the work was under the charge of General Gillmore, with the following assistants in local charge at the work: Captain

* Rep. Chf. of Engrs., 1890-II-1265, and 1891-III-1507.

William Ludlow, Captain D. P. Heap, E. Sherman Gould, C. E.; Captain J. C. Post, S. L. Fremont, C. E.; Captain B. D. Greene, Lieutenant T. N. Bailey, and Lieutenant O. M. Carter. Since 1888 Captain O. M. Carter has been in charge, with Mr. A. S. Cooper as assistant.

St. Johns River Jetties.

The St. Johns River has the peculiarity of being the only large river on the Atlantic seaboard of the United States which runs from south to north through the greater portion of its course. Its total length is over 400 miles. In a portion of its course it is subject to marked changes of level due to excessive rainfall. These changes induce cutting of the banks and other characteristics of sediment-bearing streams. For its entire length it is, however, practically a chain of lakes joined by narrow reaches, as signified by its Indian name "Welaka." These lakes act as settling basins for the sand and silt brought from the narrow reaches above them, so that even above the influence of the tide, the St. Johns ceases to be a sediment-bearing stream.

The tide is felt as far as Little Lake George, 100 miles from the mouth. At Jacksonville, 23 miles from the mouth, the mean range of tide is 1.02 ft.; at Mayport, 1.7 miles from the mouth, 4.34 ft.; and at the mouth, 5.2 ft. At the mouth, between the jetties, the ebb currents begin from 1½ to 2 hours after high water, and the floods about 2½ hours after low water. The duration of the ebbs may be taken as 6 hours and 52 minutes, and of the floods, 5 hours and 33 minutes.

Though the channel depths of the river vary greatly, between Jacksonville and the mouth a least channel depth of 20 ft. is found, excepting through two reaches, aggregating in length 8.5 miles. The minimum depth is 12½ ft. At the mouth, the flood and ebb volumes of flow have been estimated to be about 1 200 000 000 and 1 700 000 000 cu. ft., respectively.

The entrance to the river is obstructed by a fan-shaped bar similar to that described at Charleston. In 1878 its length from shore to shore, measured along its crest, was 3½ miles, the most salient portion being about ⅝ mile to the seaward of the straight chord joining its shore ends. The mouth of the river was about opposite the middle of the bar. The river channel, with mid-depths of over 25 ft., passed from the entrance close along shore to the south for about 1 mile.

From this permanent, deep channel, one or more channels radiated across the bar to the sea, on lines between the axis of the river mouth prolonged and the south shore, shifting under storm action with great rapidity, to the bewilderment of the local pilots. It is related that on one Christmas Eve a small fleet of vessels, including one steamer, was lying inside the mouth, blocked on their passage out by the shoaling of the channel. All hands went on shore to celebrate, leaving the cook alone on the steamer. During the night a west wind with a strong ebb broke the steamer from its moorings and the terrified cook found himself drifting helplessly seaward to what seemed a certain death on the bar. His satisfaction may be imagined when he discovered that the breakers were passed safely, the vessel having followed a new channel, cut by the storm which had filled the old. This was promptly buoyed and became for the time being the ship channel. The low-water depth in the channel across the bar varied from 6 to 8 ft.

The bar is of sand, and is of drift and wave formation. The coast drift is in both directions, with a decided resultant movement to the south. The extent of the shoal to the north of the entrance is due largely to Fort George Inlet, ¾ mile to the north. The widest portion of the bar is to the south of the river mouth.

The first appropriation for the improvement of the channel over the bar at the mouth was made in 1852. Ten thousand dollars were expended in dredging in 1853–55, but the improvement was not permanent. In 1853 Lieutenant H. G. Wright (later Brigadier-General and Chief of Engineers, now retired) submitted a report, based on a survey made by the United States Coast Survey. The report describes the bar as a drift and wave bar, and recommends the deepening of the channel across it by confining the currents by two jetties, built on the shoals to the north and south, substantially in the manner adopted 25 years later. No action seems to have been taken on this report. The report is interesting, particularly in view of the early date at which it was submitted.

Between 1870 and 1873 \$50 000 were expended in dredging operations. As reported from the first, these operations were not intended to afford more than temporary relief. Each long storm obliterated all traces of previous work. In 1872 General Gillmore reported that permanent improvement could be hoped for only by the application of the jetty system. He hesitated about recommending this on account of its great cost.

In 1878, after consulting with Mr. James B. Eads, C. E., the citizens of Jacksonville presented a memorial to Congress, requesting that a system of permanent improvement be adopted for the entrance to St. Johns River. With the appropriation of $10 000, made in that year, the necessary surveys were made. A project was submitted by General Gillmore in 1879, under which work since then has been carried on. Two curved jetties are being constructed, springing from the opposite shores near the entrance and converging until on the crest of the bar they are 1 600 ft. apart. From that point they are to be parallel through the length to which it may be necessary to prolong them. The jetty channel is located on the line occupied by the best of the temporary northern channels. The depth to be attained is 15 ft. at mean low water. It is expected that the jetties will maintain generally a depth sufficiently greater to allow a temporary shoaling from storm action. The jetties were to consist of a foundation mattress of logs and brush, with a superstructure of rip-rap. According to the original project the jetties were to be submerged. The present plans permit them to be raised to any necessary height.

On June 30th, 1892, the north jetty was 10 991 ft. long. All of the jetty except a shore connection, 360 ft. long, and a length of 225 ft. where there are two courses of mattresses, consists of a foundation of mattresses varying in width from 40 to 120 ft., with a superstructure of rip-rap. The shore connection is a pile, brush, and rip-rap dike. The level of the crest can be seen on the profile (Plate VII). Up to June 30th, 1892, 123 137 sq. yds. of mattress, 90 594 cu. yds. of stone, 5 819 cu. yds. of oyster shells and 565 cu. yds. of concrete had been used in the construction of the jetty.

The south jetty at the same date was 8 293 ft. long. The width of the foundation mattress varies from 20 to 120 ft. A second course of mattresses is laid for 3 209 ft., and other courses of varying length to a ninth, which is 40 ft. long. Since 1888 mattresses have been used only in the foundation course, the remainder of the jetty being built of rip-rap. Four sets of spurs were built at a narrow portion of the jetty. The crest heights can be seen on the profile (Plate VII). Up to that date 217 650 sq. yds. of mattresses, 94 925 cu. yds. of stone, 3 730 cu. yds. of shell and 218 cu. yds. of concrete were used in the construction of the jetty. The total cost of the work, including a survey of the upper river and a month's dredging by the steamer *Woodbury*, has been $1 003 000.

The jetties have deepened the channel over the bar to 11½ ft. in the south channel and 10½ ft. in the north channel. Work for deepening the shoalest portion of the reach between Jacksonville and the bar by dredging and the construction of dikes, under a project approved by the Chief of Engineers, is being carried on by the County of Duval, under the charge of Mr. J. H. Bacon, formerly U. S. Assistant Engineer.

Materials and Methods; Mattresses.—The mattresses used until 1888 were of logs and brush, similar to those used in the Charleston jetties. In the St. Johns work they proved very unsatisfactory. Where the bottom was irregular, the mattresses broke, and many logs were loosed from the binders and lost. The mattresses were not strong enough to be handled in a seaway and strong currents, and some were broken and lost before being placed. When in place they were frequently underscoured in positions where there was a strong current, or where a difference of head was developed, causing a settlement which amounted to 20 ft. at one point. They were not easily covered by sand, and so were long subjected to the ravages of the teredo. In shoal water the brush disappeared completely in less than two years, through wave action and the teredo. For these reasons they were discarded, and a brush fascine mattress was used, which, as finally adopted, is described in the specifications as follows:

"The mattresses will consist of a layer of closely compacted fascines of live brush * * * * crossed at right angles by a second layer of like fascines, placed at intervals of 6 ft. The brush must be carefully laid so as to break joints and make a continuous fascine extending completely across the mattress. The fascines must contain as much brush as may be required, and must be compressed tightly by an approved form of choker to a diameter of 9 ins., at intervals of 2 ft., where they must be bound firmly with iron wire of approved strength. The fascines must be firmly held between binding poles made of live saplings of yellow pine, or other timber of a kind approved by the engineer in charge. These must be straight and of slight taper and must be not more than 5 ins. in diameter at the butt, nor less than 2 ins. in diameter at the tip. They must be spliced together with long scarf joints in a manner satisfactory to the engineer in charge, so as to extend completely across the mattress. Either one or two layers of these poles will be used at the top and at the bottom of the mattress, as may prove necessary for holding the fascines until in place in the jetty and ballasted. The binders in each layer must be placed parallel to each other at intervals of 6 ft. * * * * The fascines and

binders must be firmly compressed and lashed together at intervals of 6 ft. in a manner satisfactory to the engineer in charge. Towing beckets, buoys and lines, and range masts must be placed as directed."

The mattresses are built on shore on ways consisting of parallel timbers about 6 ft. apart, supported on piles, with a slope toward the water of about 1 on 12, and with their lower ends at the level of high water. The tops of the ways are arranged for launching the mattress with as little friction as possible. One method is to have a longitudinal groove in the top 1 in. deep. The bottom and sides of this groove are smooth and coated with graphite, tallow or some other lubricant. In the grooves are laid strips of 2-in. lumber, with the bases and sides smooth and lubricated. These are fastened in place temporarily and have light lines attached, for drawing them ashore after the mattress has been launched. On the ways, at right angles to the timbers, is placed the first layer of binders, and on these, a second layer, forming a grillage with 6-ft. spaces. The binders are spiked together at each intersection. On the grillage, parallel to the top layer of poles (to reduce the distance from the sand when in place), is placed the lower layer of brush fascines. These must be of small brush, choked as tightly as possible before binding with a heavy rope and levers, as described for military fascines. When finished, they should be absolutely compact and hard where bound by the wire. Between the wires they should bulge out so as to extend to the base of the grillage. The fascines are jammed together in the mattress by levers. On this layer is placed the second layer at the 6-ft. intervals. On these comes the top grillage, with its intersections over those of the lower grillage. At each intersection of the lower grillage has been lashed a piece of manilla rope, ½ in. in diameter. This is led up between the fascines as they are placed. After the top grillage has been placed, the two grillages are drawn together by levers to the full strength of the rope, and lashed.

The mattresses are placed in the jetty with the lower layer of fascines at right angles to the jetty axis. The mattress as used has been 120 x 75 ft., the greater length (the side) being across the jetty. Towing beckets are placed at intervals across the ends. At the sides, at the extremities of the line which is to lie in the axis of the jetty, are placed range masts, long enough to have their tops 6 ft. above high water when in place, and also wood buoys, anchored to the mattress

with ropes, for use should the range masts be accidentally carried away. The mattress being finished, at the next convenient high water the temporary fastenings are removed from the slide strips, and a tug draws the mattress from the ways. The ends are immediately made fast to flats loaded with ballast stone, by lines running through the beckets and fastened to the flats in such a manner as to permit a gradual paying out. To increase the buoyancy of the mattress, the grillage poles are frequently barked and seasoned. At times, also, small flats are floated over the mattress and fastened to it.

Just before the end of the ebb, the tow, consisting of one tug, the mattress between the two flats, a rowboat for the inspector and a heavy rowboat with crew, for setting out anchors, starts. The start is so timed that the mattress will be in position at low water slack. Arrived nearly at the site, a line is passed from a mooring attached to a heavy anchor already in place inside the jetty, the tug casts off its line and the flats and the mattress are swung by the last of the ebb into position across the end of the jetty. Other anchors are run out, until the tow is held by from four to six anchors, placed at the diagonals, and one shoreward and one seaward. The lines from the anchors are passed around capstans on the flats, and the mattress is carefully adjusted by signals from the inspector in his boat, so that the inner range mast is close to the outer range mast of the mattress last placed, and the two range masts of the new mattress are in line with the shore range. Should any of the range masts be carried away, the corresponding buoys are used. At a signal from the inspector, the stone is thrown from the flats on to the mattress as rapidly as possible, the mooring lines being paid out as the mattress sinks. Just before the mattress touches the bottom, a last adjustment is made. After the mattress is once in place, it cannot be moved. The flats are then drawn together across the mattress, and the remaining stone is distributed as evenly as possible over the surface of the mattress. Soundings are taken by the inspector just before and just after the mattress is placed. After it is in position and ballasted, transit observations from shore on the range masts give the necessary data for plotting its position on the progress charts. Five feet leeway is allowed the contractor in placing the mattress in the designated position. An expert foreman will place his mattress within this limit with ease.

The brush mattresses are so strong and flexible that they can be

handled in a seaway which would wreck a log mattress. The passage of a wave under the mattress can be followed easily by the undulation. The upper layer of fascines with its grillage forms a series of shallow cribs which assist in holding the stone. No under-scour has been observed with the long brush mattresses of the St. Johns work. The length is also sufficient to make an efficient apron along the sides of the superstructure. To decrease the chance of scour along the edge of the mattresses and to increase the width of apron along the inside of the jetty, the range masts are placed alternately 45 and 55 ft. from the outside or sea ends of the mattresses, thus bringing the inside ends alternately 75 and 65 ft. from the jetty axis. The use of mattresses above the bottom course was found to be inadvisable, the loss by the teredo was too great. Wood cannot be used in the jetties excepting where it quickly gains protection from the sand.

Experience at St. Augustine and St. Johns River has shown the approximate cost of a 120 x 75-ft. mattress to be as follows:

2 747 cu. yds. brush, labor at 15 cents per hour.......	$57 96
Hauling to fascine rack with cart and driver, at 25 cents per hour....................................	110 59
Labor of making and handling 9 660 ft. of fascines at 15 cents per hour..................................	96 60
Cost of 8 906 linear feet poles, delivered at ways.......	60 00
600 lbs. 60 D nails at $2 60 per 100....................	15 60
313 lbs. ½-in. Manilla rope at 13⅜ cents per pound......	41 86
426 lbs. No. 14 iron wire at 14 cents per pound........	19 17
Labor of assembling mattress at 15 cents per hour.....	144 27
" launching " " "	21 50
" sinking " " "	27 00
Superintendence at $75 per month.....................	18 75
Total..	$613 30

or 61⅓ cents per square yard.

The contract price for log and brush mattresses in place varied from 54 to 75 cents per square yard, and of brush fascine mattresses in place from 70 to 74 cents per square yard.

Stone.—Where the cross-currents were not too strong and below low water, the light Florida limestone was found to answer for the super-

structure. Where exposed to wave action and strong currents, a heavier stone from the North had to be used. The stone was all placed by hand. It is bought by the ton, the weight being determined by the displacement of scows or flats. At first all stone was bought by the cubic yard, but the impossibility of accurate measurement of rip-rap, and the frequent disputes as to volume which this method entailed, caused it to be discarded. The following method was devised, to prevent errors in gauging the flats arising from wave action and the varying density of the water at the mouth of the river.

A small well is built through each end of each flat, close to the keel and just inside the rake. Immediately before a loaded flat is taken to the jetty, a tube, 4 ins. in diameter, with the bottom pierced with a small hole, is lowered into each well in succession. The top of the tube is flush with the deck, and through its lid a rod passes freely, having a float attached to its lower end. Distances from the water-line on the float are marked on the rod. As soon as the water in the tube ceases to rise, which will be when the mean level of the water outside is attained, the reading is taken; at the same time the density of the water is read with a salinometer. With these readings the displacement of the scow is obtained from a table previously calculated for that scow. As soon as all of the stone which has been accepted has been unloaded, the scow displacement and density of water are measured again. The difference gives the weight of stone. The method has been found to be easily applied and accurate. Since the flats have to be loaded evenly for safety in the seaway, the two wells are found to give the same results in all practical cases as would be found from four wells at the corners.

Shell.—Oyster shells were used for a time as hearting. When they can be deposited quickly and protected from wave action, they are found to make a cheap and tight hearting. Loose shell dumped near a hole under the jetty quickly stopped the flow and caused the sand to collect.

The contract price for stone varied from $3.10 to $4 per cubic yard of 2 700 lbs.; and from $2.07 to $2.57 per ton of 2 000 lbs. Under the specifications for purchase by the short ton a lighter stone was allowed to be used, and the stone delivered consisted of Florida limestone, weighing from 2 000 to 2 100 lbs. per cubic yard, and Northern stone, which weighed from 2 400 to 2 700 lbs. per cubic yard. The

price of oyster shell varied from \$1 to \$1.40 per cubic yard, according to the position where used.

Shore Connections—North Jetty.—The inner end of the north jetty, as first built, was twice flanked by the sea, and a dangerous cutting of the beach took place. In 1887 the channel was closed and the jetty carried beyond high water-mark by a pile dike. This consisted of two rows of palmetto piles, 6 ft. apart, tied together and braced. The piles were driven by the aid of the water-jet. The space between the piles was filled with stone, resting on a log mattress foundation. The strong currents induced great scour and cutting of the beach as the piles were placed, and after the hearting was in position, under the dike. The mattress proved too stiff to follow the lowering sand, and the hole under the dike attained a depth of 10 to 15 ft. Finally, the mattress, where necessary, was torn out and the holes filled with brush in bundles and rip-rap stone. Wings of rip-rap were built on the two sides of the dike, to stop the scour of the racing waves. Within a year the beach had built to the level of the top of the dike, the sand advancing from the north over the lowered beach like a great wave. The dike is now buried completely.

The south jetty shore extension was made with rip-rap, capped with concrete blocks, over the old mattresses. Immediately after the work was finished a fill began on the south side, while the north side was cut, showing that the sand on this side was supplied from the south. By removing a portion of the jetty capping, just beyond the high water-line, a breach was made about 20 ft. long, with its crest at about half-tide level. A large supply of sand was swept through this breach at each flood.

Sand Catches.—Cheap and efficient sand catches were made by an ordinary post and rail fence. The posts were set up, and a couple of boards, with an interval an inch wide between them, to reduce the wind eddy, were nailed on just above the sand level. As the sand built up, other boards were added, until the desired height was reached. This style of sand catch was used earlier, at the Cape Fear work. Another efficient catch was made from old cement barrels, filled with sand.

Capping.—The experience at Cape Fear had shown the necessity for smooth, easy slopes for the portion of the jetty exposed to wave action, where very heavy blocks could not be obtained. Accordingly, when, in 1888, it became necessary to raise the level of the inner end of the

north jetty above the low-water level, in order to build out the beach and to strengthen the shore connection, recourse was had to light blocks of concrete, since stone in proper sizes was too costly. These were laid with a crest 2 ft. wide, 5 ft. above the level of mean low water, and side slopes of 1 on 3. The blocks had an exposed surface of 4 × 2 ft., and were 18 ins. deep. To permit construction to be carried on during the falling as well as during the rising tide, and to allow each block to settle freely, all the sides were made vertical, giving a lozenge-shaped vertical section, perpendicular to the jetty axis. To break joints properly, the blocks were laid herring-bone fashion, as in brick sidewalks. Each block weighed 1 700 lbs. When left loose on top of the jetty, they were moved by the waves easily. None were ever disturbed after having been placed. The heaviest waves slipped smoothly over the slopes without their power having been developed. The joints between the blocks and the lewis holes through them were found advantageous for permitting the escape of air from the rip-rap hearting during wave action. Later, a small section 6 500 ft. from shore was capped with concrete blocks, weighing 1 600 lbs., of hexagonal horizontal section, with vertical sides 18 ins. deep, and laid with side slopes of 1 on 2. These proved easy to handle and to place, but were just under the limit of weight. One or two blocks on the inner slope were jumped out of place during storms.

Tides and Currents.—The mean range of tide at the mouth of St. Johns River has been stated to be 5.2 ft. The tidal curves given on Plate VIII show the tidal range on June 5th, 1890, and the mean velocities on the same date. Station No. 1 was on the crest of the bar, on the edge of the channel, 2 000 ft. outside of the outer end of the south jetty. Station No. 2 was in the south jetty channel, 2 000 ft. inside the outer end of the south jetty. Station No. 3 was in the north jetty channel, directly opposite the angle in the jetty. In 1879 the mean flood and ebb velocities in the river at Mayport were estimated to be 1.6 and 2.2 ft. per second, respectively. The tidal curves of Plate VIII may be considered to be fairly typical. The current directions at Station No. 1 were inclined toward the south jetty channel during flood, and away during ebb. At Station No. 2, south jetty channel, the directions were in during flood, and out during ebb. At Station No. 3, north jetty channel, the directions were in during flood, and out during ebb. At this last station the influence of

the flow across the jetty during both flood and ebb was seen more plainly than at Station No. 2. The slight development of flood velocities and the strong ebb velocities at all of the stations will be noted. In general, it has been observed that the flood pours in across the jetties from both sides and through the opening between the jetties, and that the high flood velocities are not found until the flow is concentrated in the interior channels; that the ebb follows defined channels as much as possible, is strongest in them, and is the controlling current in the channels across the bar; that head and velocity of ebb currents are decreased as the distance from the mouth increases, by the spill over the tops of both jetties; that the submerged jetties control the bulk of the ebb flow, guiding it with least loss of head when the current is parallel to them; and that the maximum flow across the jetties on both ebb and flood is dependent on the direction of the wind, that is, a strong wind from the north will increase the relative flow across the north jetty during floods and decrease it during ebbs, and the reverse.

No diminution of the tidal range or volume in the river has been observed since the work began.

Jetty Location and Sand Movement.—The work at the mouth of St. Johns River illustrates clearly the fact that the drift and wave bars of our southern coast can be molded at will by the engineer. A new channel can be formed on any desired line. The cost of forming and maintaining this channel will vary with the location and form given the jetties, and the best position will be that in which this total cost is least. Many conditions must be considered when the location is selected, and, the location having been made, there remains the choice of methods for compelling the necessary scour; so that it is not surprising that engineers should differ. After a work has been started, the knowledge gained by the work itself may show that another plan might have proved more economical and make later criticism easy. The plan adopted by General Gillmore for the St. Johns improvement is similar to that adopted earlier at Charleston, and is nearly on the lines recommended for parallel jetties by Mr. James B. Eads, C. E., to the citizens of Jacksonville.

The history of the sand movement between the jetties may be summarized as follows: In 1879 (see Plate VII) the project was formed. There were then two channels across the bar, one leading out between

the lines of the proposed jetties, and one, slightly deeper, on a straight line running southeast from the mouth. The north jetty is so placed as to run on nearly the shortest line, in the shoalest water, from a safe point on shore, north of the river mouth, to the north side of the channel over the bar. The proposed south jetty crossed the permanent deep channel leading to the south along the coast, and converged toward the north jetty, until at the channel over the bar, where the work was required, the desired contraction was attained, when it became parallel to the north jetty.

In 1883 the north channel of 1879 had been closed by a sand bank, bare at low water, reaching to the site of the south jetty, and the sailing line was across the south jetty, through the south channel. The north jetty was too short to have any effect beyond the development of a current around its ends, cutting back the beach. The south jetty foundation was extended to 5 000 ft., and, excepting in the sailing gap where an 18-ft. channel was left, it was built nearly to low water. From its position, it acted as a partial dam, directly across the main channel. The effects were: first, a portion of the ebb flow of the ship channel was deflected to the northeast; second, the channel shoaled slightly midway between the jetties; third, there was great scour at and near the sailing gap; fourth, a portion of the dammed-up water had passed out, close to the south jetty, cutting off the edge of the sand bank (Wards Bank) and forming a narrow channel directly seaward.

In 1885 the channel to the north across the line of the north jetty had become more clearly defined; the shoaling of the "middle ground" in the ship channel had continued, and the channel north of the south jetty had enlarged. The north jetty had just been extended from both ends and its effects had not yet showed themselves.

In 1886 the middle ground had shoaled to 14 ft.; the channel to the north had grown and had undermined the end of the north jetty. Its inner end was also flanked. The south jetty channel had enlarged and become the main ship channel. The shoals north of the south jetty had grown to their greatest size.

In 1888 the old sailing gap in the south jetty had been closed for over a year. The middle ground had shoaled to 10.4 ft. The inner end of the north jetty had been secured, and the beach there had begun to build. The north jetty had been extended to stop a portion of the

flow across its line, but the extent of the loss from the ebb currents there is shown by the scour along and in advance of its site. The futility of the expectation of building the jetty in shoal water had been shown by the scour, produced by the jetty itself as well as by the water diverted across it by the damming action of the south jetty. The north jetty had begun to turn a portion of the flow which formerly crossed its site in the direction of the bar channel. A portion of Wards Bank had been scoured away. The south jetty channel had widened and deepened, and the least depth across the bar was 13 ft. South of the south jetty there had been a marked shoaling in the old channels.

By 1890 the north jetty had been extended to the same length as the south. The effects of the 1890 work are seen in the map for 1891, in the straightening of the old permanent channel, just outside the river mouth; in the disappearance of Wards Bank and the opening of the new straighter sailing line between the jetties to the north of the middle ground shoal, on which the depths had decreased to 9.4 ft. Unfortunately, in October, 1889, work had to be suspended, owing to a lack of money, and, during the suspension, the jetty channel was forced by the northeast gales to the south, across the line of the south jetty. This bending of the channel has been a source of great difficulty since then. The only effective work to be done was to extend the south jetty. This could not be extended without closing the commercial entrance to the port to an unwarrantable extent. At the same time the scour through the channel deepened the site over which the jetty must be built, and this increased its height and cost. Under these circumstances work has been confined to stopping the escape of water around the end of the north jetty by a slight further extension, by raising the jetties to the level of mean low water, and by pushing the south jetty gradually seaward.

The fall and winter of 1891–92 was unusually stormy, so that on the map of 1892 the channel is found pushed far to the south, and the entrance difficult. On the other hand, the greater portion of the sand which formerly had obstructed the water-way between the jetties is found to have been scoured away. The deep channel from the river extends in nearly a straight line as far as the end of the south jetty, and the north jetty channel extends with a depth of 12 ft. to within 200 ft. of the outer slope of the bar. Once this channel is opened, it

will be a comparatively simple matter to control the flow sufficiently to obtain the required depth across the bar.

Remarks.—The six years' experience of the writer at this work has led him to the following conclusions. In a work under conditions similar to those existing at the mouth of St. Johns River (where the tidal flow is ample, and where the sand movement is large and from the north), two jetties are required. Their location should be such that as much advantage as possible may be taken of any conditions which permanent deep channels prove to have had a controlling power. To this end permanent deep channels should be followed, as far as consistent with economy in jetty length and construction and with a proper direction for navigation purposes. When permanent natural channels must be crossed, they should be deflected and not dammed, so that the channel first scoured by the work shall be in or near the position of the proposed channel.

The jetty on the side opposite the source of the moving sand, in the case in point, the south, probably will be always the guiding jetty and the channel probably will skirt it, at least through the most precarious portion of its course. Through this portion of the course it should be straight, or concave toward the channel. The north jetty will be needed to prevent the loss of water through false channels across its line. These may be formed by the excess of head before the main channel is fairly opened, or by the deflection of the main channel during storms from the south the north jetty will act, to some extent, also as a barrier against moving sand; but unless it be given an excessive height, this barrier must soon be crossed. If the necessary height be given, where the volume of moving sand is as great as along the Florida coast, the building out of the north shore may entail a speedy extension of the jetties, as well as increased first cost due to the great strength required for a breakwater, such as this then becomes. When the moving sand does cross the north jetty, it still remains as a solid core, necessary to prevent the formation of false channels across the sand dike. If the south jetty be prolonged sufficiently, it will be easy so to proportion the width of entrance to the tidal prism of the basin within as to maintain velocities sufficient to sweep into deep water the sands which encroach on its northern edge.

The height of the jetty should be sufficient to control the ebb flow to the required extent, and no greater. An increase of height calls for

a rapid increase of strength to resist the greater amount of wave force which must be met and absorbed by the jetty. Where an increase of tidal basin is not required, the jetties should run on the shortest line to that point beyond the entrance at which the condition of the natural channel shows that the ebb currents require aid to maintain the channel depths. An increase of tidal basin, therefore increased power at the bar, may be obtained where needed by a wider divergence of the inner ends of the jetties.

Like all the works along the coast, the St. Johns work has been hampered by irregular and insufficient supplies of funds. The immediate needs of navigation had to be provided for. It was impossible for the engineer in charge to foretell when, if ever, a future appropriation would be made. It was therefore impossible to carry on continuous work with the most economical methods, or to meet emergencies as they presented themselves. Like most unwelcome things, they seemed to have the faculty of coming forward exactly at the wrong time.

The ultimate height and length of the jetties will be controlled by the necessities of the work. The marked difference in level of the planes of mean flood and ebb flow make easier the problem of controlling the ebbs without too great an interference with the floods. The work already done by the jetties has been enormous. Up to June 30th, 1892, the total scour has been about 4 500 000 cu. yds., and the cost of removal (the cost of the jetties) about 21 cents per cubic yard, while the cost of dredging in 1872–73 was over 50 cents per cubic yard. A portion of this material has been deposited beyond the crest of the bar in moving it seaward, but the greater portion has been passed to the south. Each year shows a marked gain of channel length on the bar crest, and it cannot be long before the required depth is attained.

This work was under the charge of General Gillmore from 1869 to 1885; of Captain W. T. Rossell from 1885-86; of Captain W. M. Black from 1886–91, and, since then, of Major J. C. Mallery. General Gillmore's assistants were Lieutenant W. L. Fisk, Captain J. C. Post and Captain W. T. Rossell. The writer is greatly indebted to the entire staff of the work for most interested and efficient assistance. His principal assistants were Messrs. A. W. Barber, D. B. Dunn, J. W. Sackett and J. H. Bacon and Lieutenant D. D. Gaillard. Major Mallery's assistant is Mr. E. W. Gieseler.

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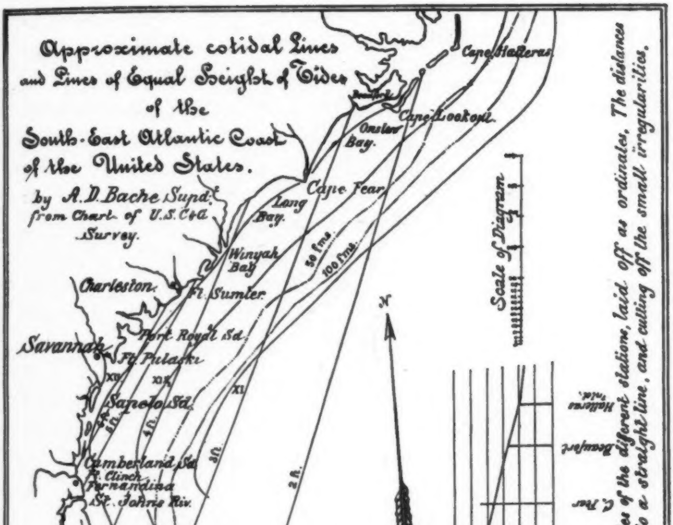
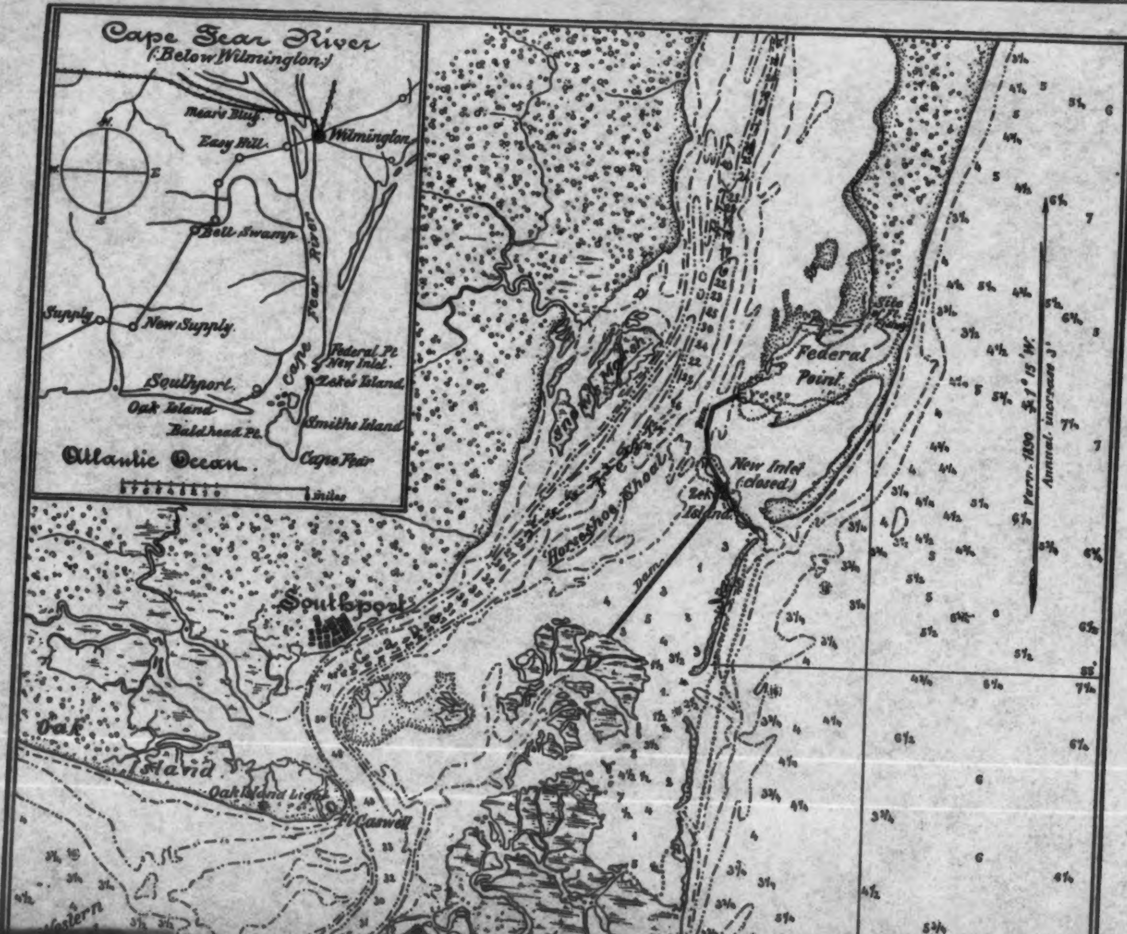
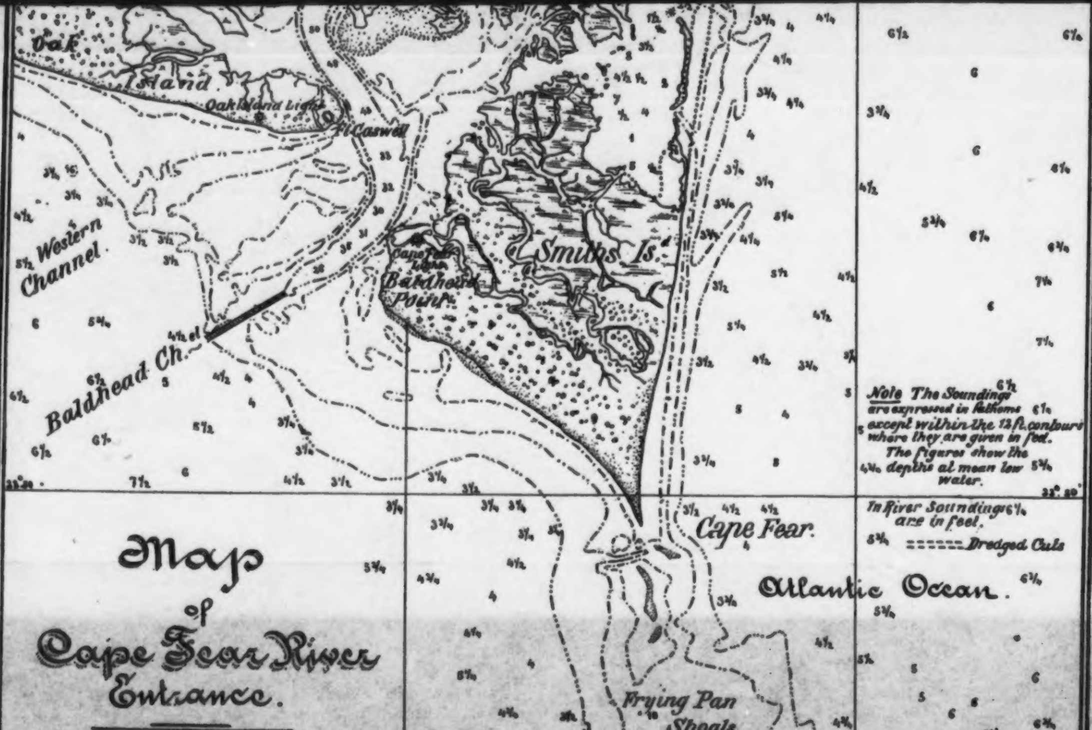
TRANS. AM. SOC. CIV. ENGRS.
BLACK ON IMPROVEMENT OF HARBORS.
PLATE I.

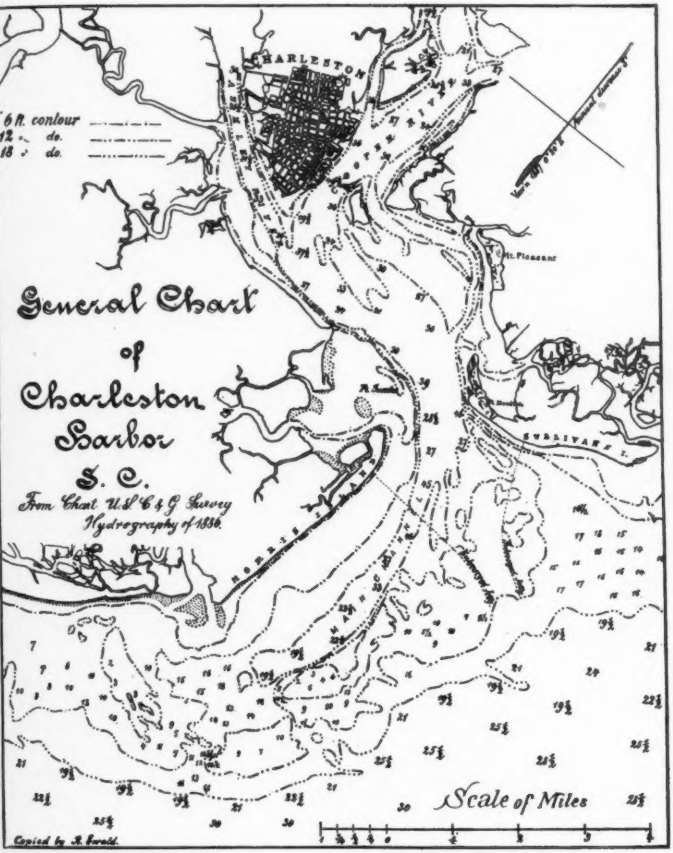


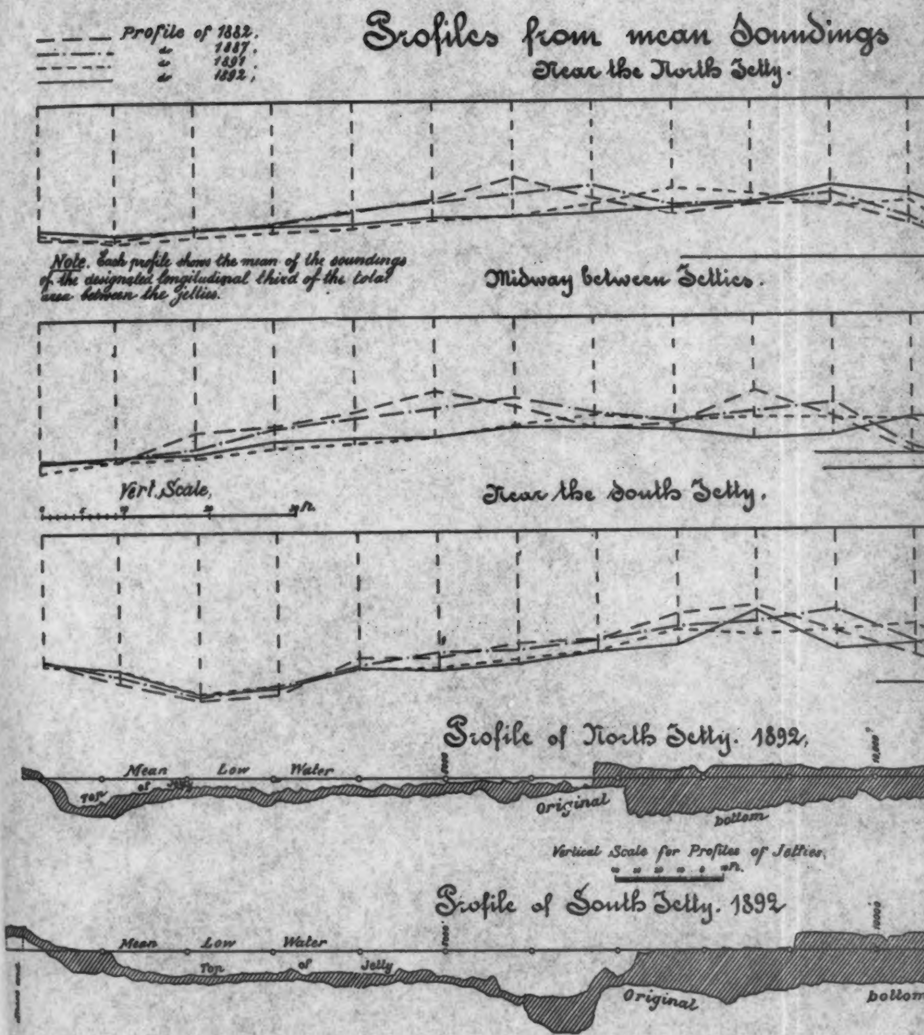


Cape Fear River
(Below Wilmington)
Mears Bluff
Wilmington
Easy Hill
Bell Swamp
Cape Fear River
Supply
New Supply
Federal Pt.
New Inlet
Zeke's Island
Southport
Oak Island
Smiths Island
Baldhead Pt.
Cape Fear
Atlantic Ocean
Miles
Federal Point
New Inlet (closed)
Zeke's Island
Horseshoe Shoal
Dam
Southport
Oak Island
Oak Island Light
Ft. Caswell
Varn. 1890
Annual increase 3'

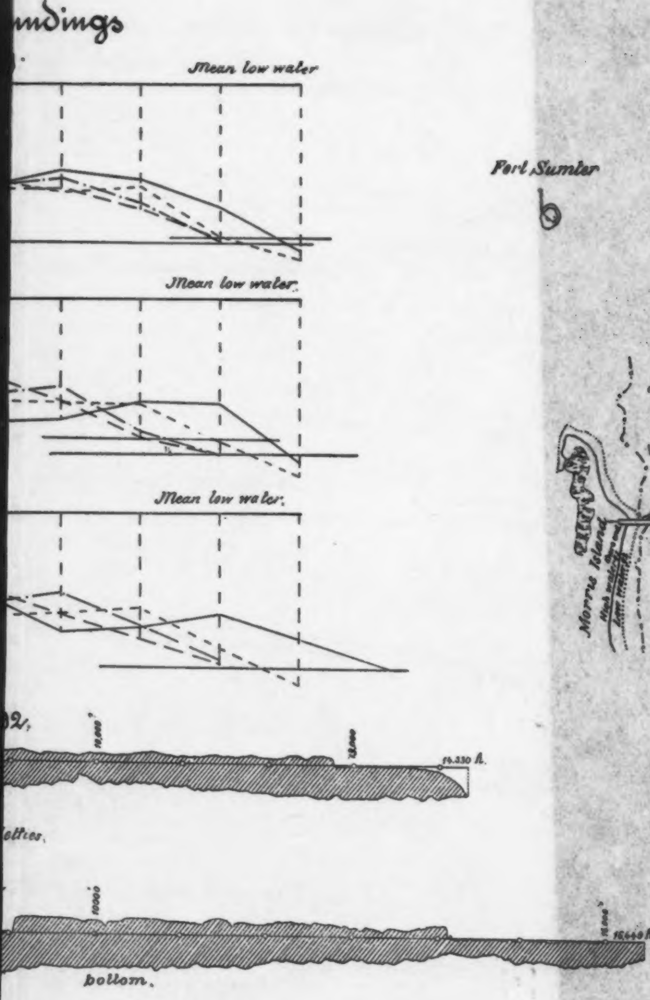

Map of Cape Fear River Entrance.
Oak Island
Oak Island Light
Ft. Caswell
Western Channel.
Baldhead Ch.
Cape Fear Light
Baldhead Point
Smiths Is.
Cape Fear.
Atlantic Ocean.
Frying Pan Shoals
Note The Soundings are expressed in fathoms except within the 12 ft. contours where they are given in feet. The figures show the depths at mean low water.
In River Soundings are in feet.
Dredged Cuts

L. XXIX, No. 610.
AM. SOC. CIV. ENGRS.
MPROVEMENT OF HARBORS.
PLATE II.


General Chart
of
Charleston
Harbor
S. C.
From Chart U.S. C & G Survey
Hydrography of 1886.
6 ft. contour
12 do.
18 do.
CHARLESTON
Mt. Pleasant
SULLIVANS I.
MORRIS ISLAND
Scale of Miles
Copied by R. Ewald.



Profiles from mean Soundings
Profile of 1882.
do 1887.
do 1891
do 1892.
Near the North Jetty.
Note. Each profile shows the mean of the soundings of the designated longitudinal third of the total area between the Jetties.
Midway between Jetties.
Vert. Scale.
Near the South Jetty.
Profile of North Jetty. 1892.
Mean Low Water
Top of Jetty
Original bottom
Vertical Scale for Profiles of Jetties.
Profile of South Jetty. 1892
Mean Low Water
Top of Jetty
Original bottom



Mean low water
Mean low water.
Mean low water.
14.330 ft.
bottom.

Fort Sumter
Morris Island
Entrance

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BLACK ON IMPROVEMENT OF HARBORS.
PLATE IV.

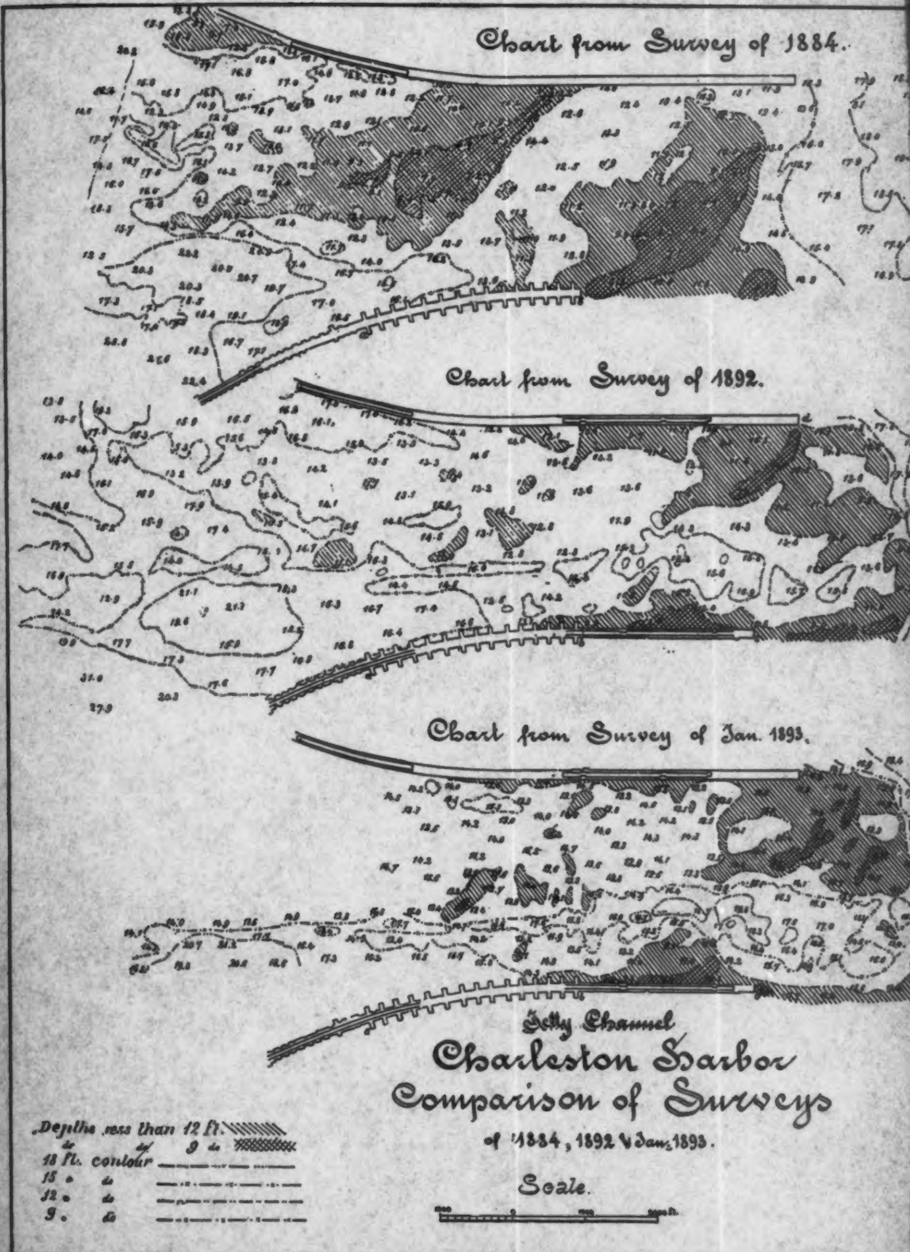


Chart from Survey of 1884.
Chart from Survey of 1892.
Chart from Survey of Jan. 1893.
Jetty Channel
Charleston Harbor
Comparison of Surveys
of 1884, 1892 & Jan. 1893.
Scale.
Depths less than 12 ft.
do do 9 do
18 ft. contour
15 do
12 do
9 do

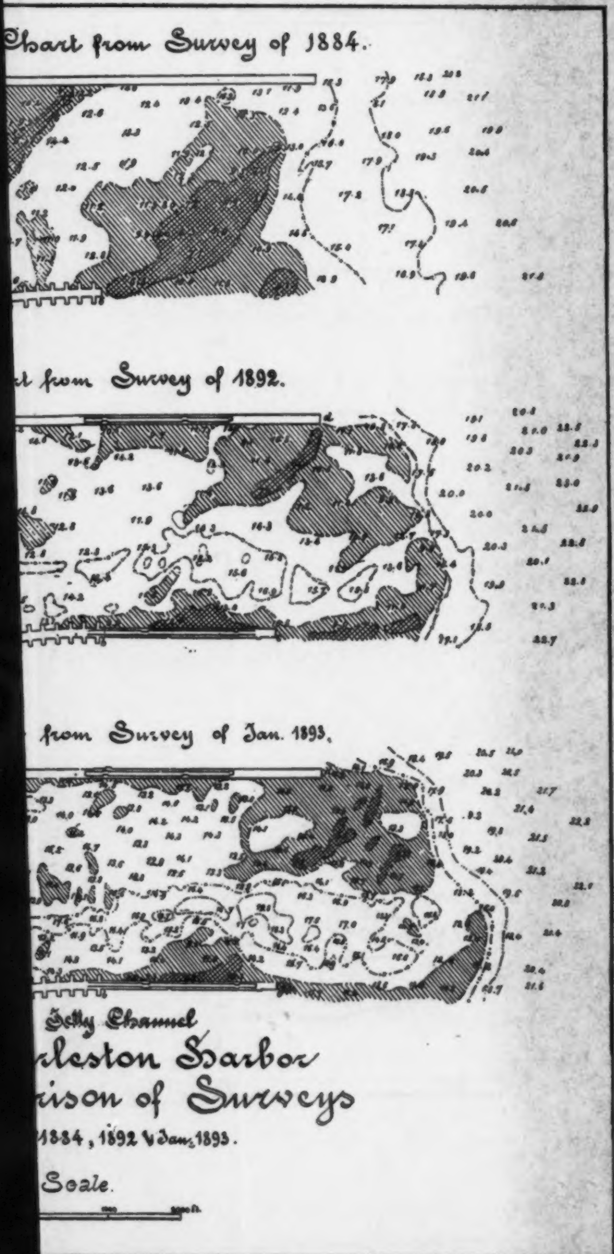
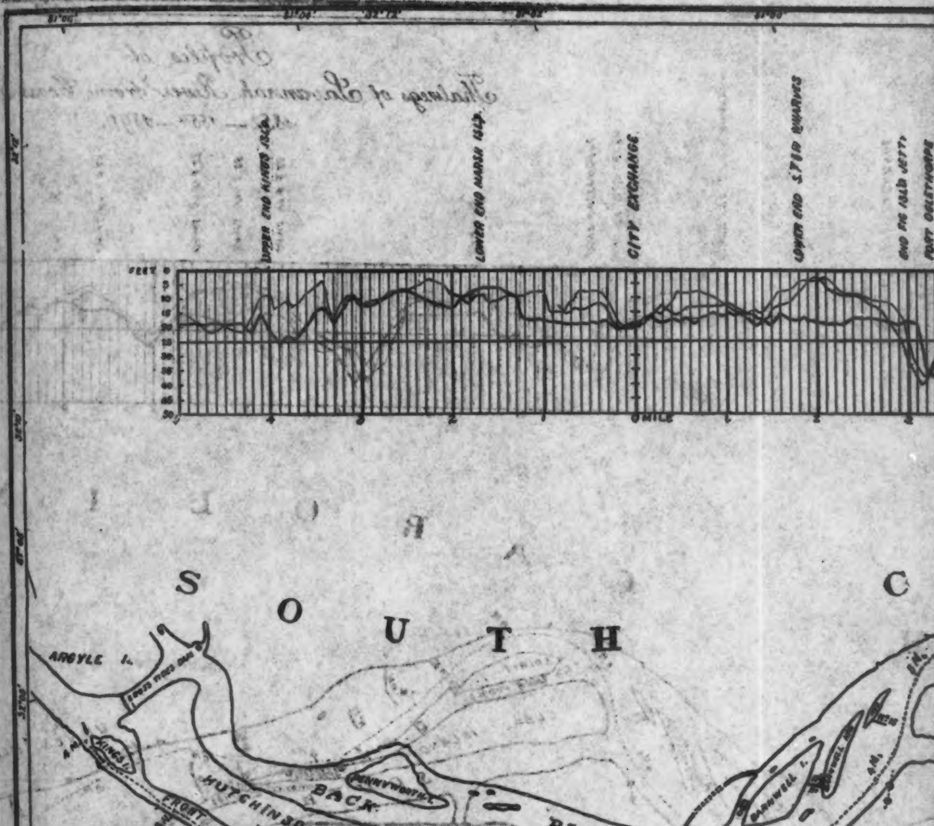
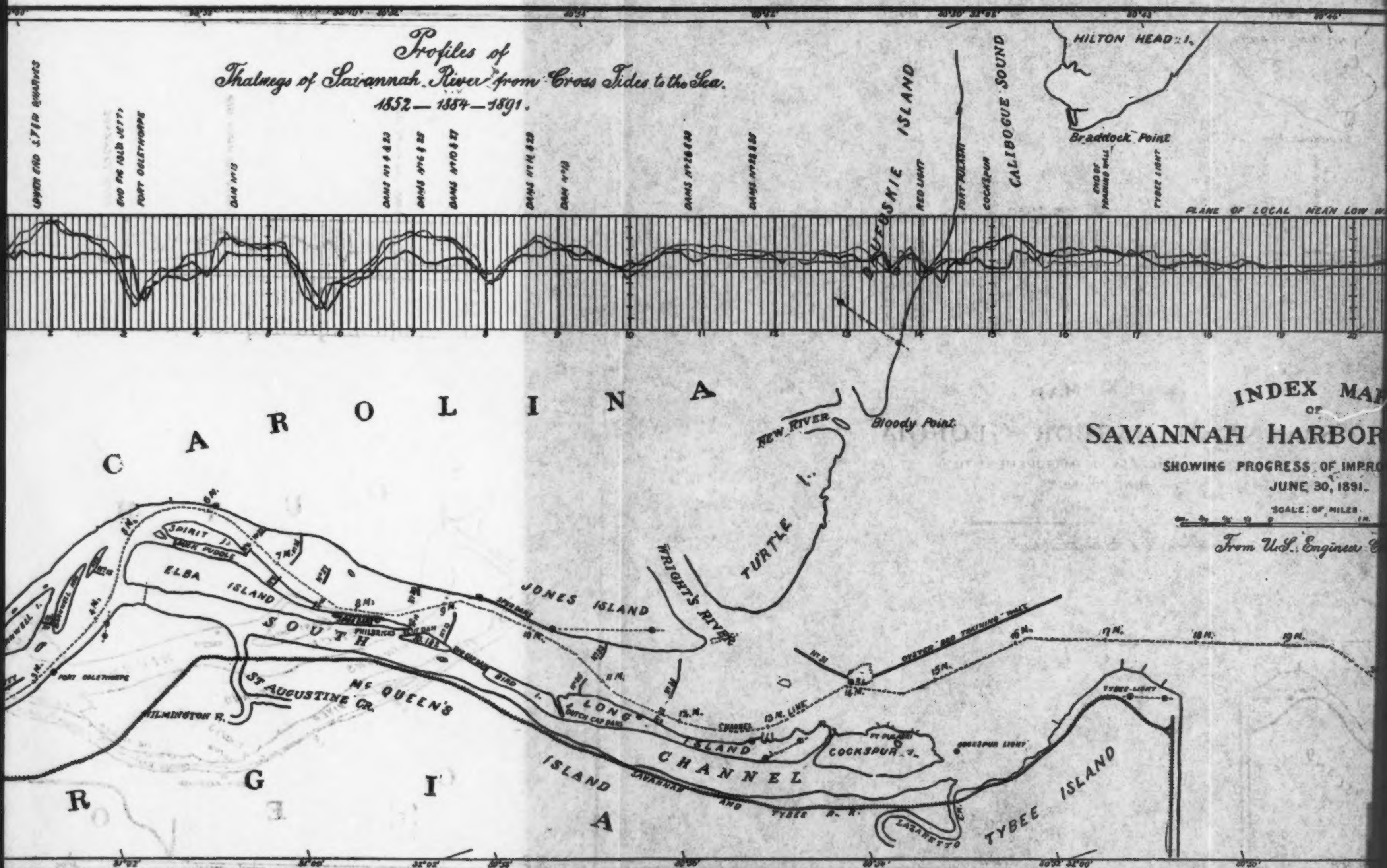


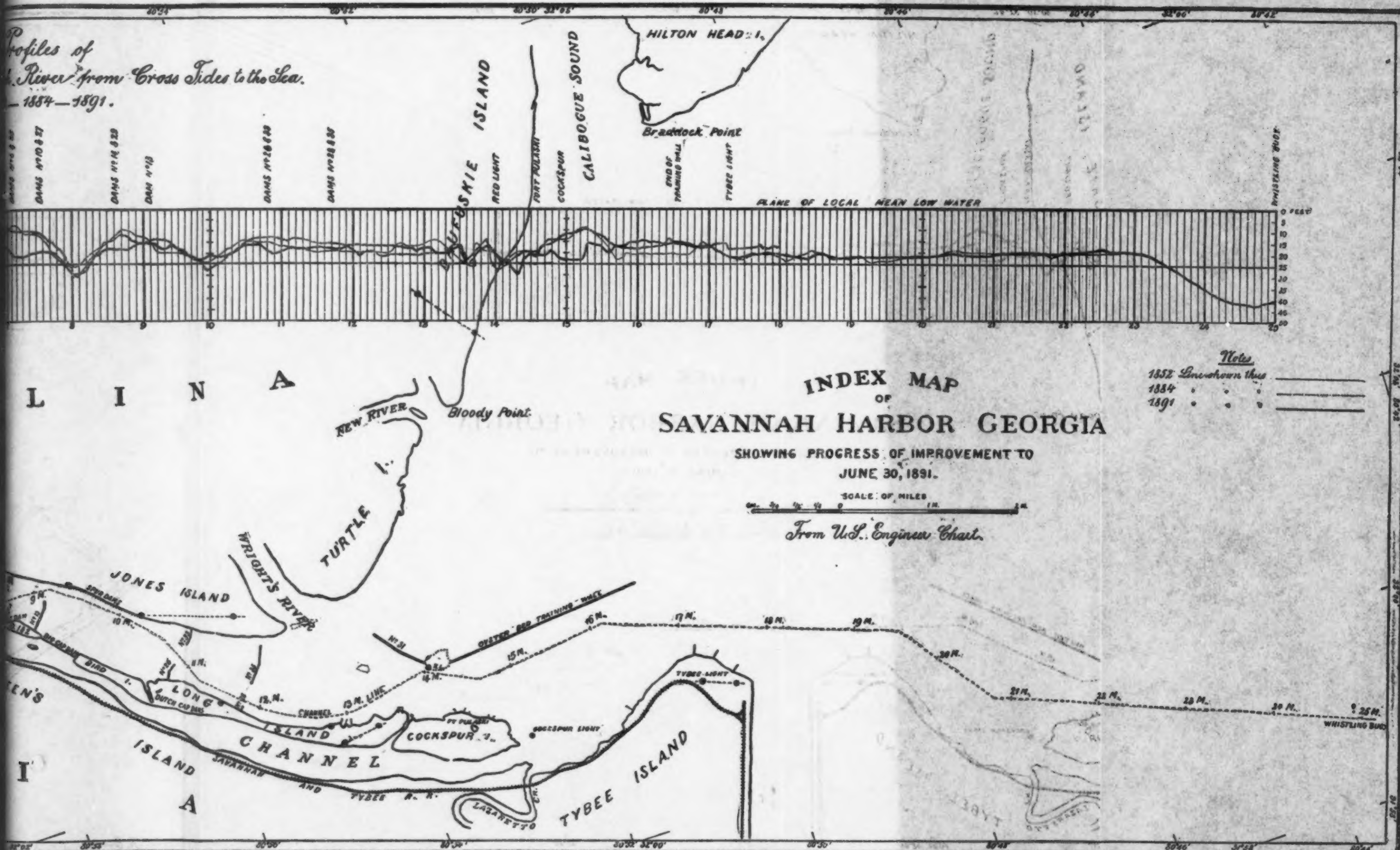
Chart from Survey of 1884.
t from Survey of 1892.
from Survey of Jan. 1893.
Jetty Channel
rleston Harbor
rison of Surveys
1884, 1892 & Jan. 1893.
Scale.

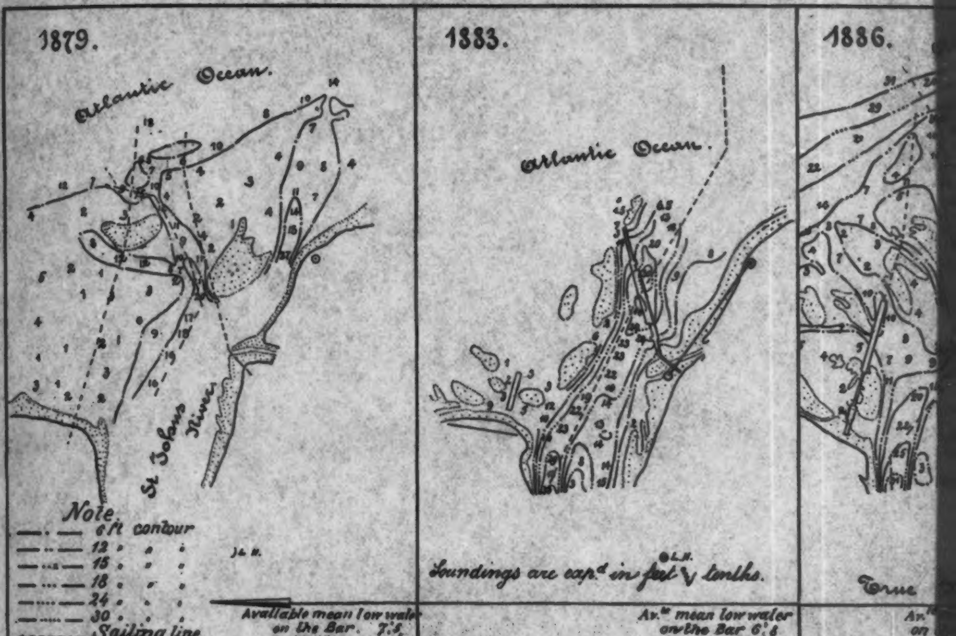


UPPER END HUNTS ISLD.
LOWER END MARSH ISLD.
CITY EXCHANGE
LOWER END S.T.I.P. WHARVES
END FIG ISLD JETTY
FORT OGLETHORPE
FEET
0 MILE
SOUTH C
GEOR
ARGYLE I.
HUTCHINSONS
BACK
RIVER
FRONT
RIVER
ISLAND
PENNYWORTH
KINGS I.
BARNWELL I.
KINSEYS POINT
FIG ISLAND
FIG ISLAND JETTY
CITY EXCHANGE
FORT OGLETHORPE
R. Ewald



Profiles of
Thalwegs of Savannah River from Cross Tides to the Sea.
1852 — 1884 — 1891.
CALIBOGUE SOUND
DAUFUSKIE ISLAND
HILTON HEAD I.
Braddock Point
PLANE OF LOCAL MEAN LOW W
Bloody Point
NEW RIVER
TURTLE I.
WRIGHT'S RIVER
INDEX MA
OF
SAVANNAH HARBOR
SHOWING PROGRESS OF IMPRO
JUNE 30, 1891.
SCALE OF MILES
From U.S. Engineer
C A R O L I N A
SPIRIT I.
ELBA ISLAND
JONES ISLAND
SOUTH
FORT OGLETHORPE
ST AUGUSTINE CR.
MC QUEEN'S
WILMINGTON R.
BIRD I.
LONG ISLAND
CHANNEL
COCKSPUR I.
COCKSPUR LIGHT
TYBEE LIGHT
TYBEE ISLAND
ISLAND
SAVANNAH AND TYBEE R. R.
LAZARETTO CR.
G E O R G I A


Profiles of
River from Cross Tides to the Sea.
1884—1891.
PLANE OF LOCAL MEAN LOW WATER
DAUFUSKIE ISLAND
RED LIGHT
FORT PULASKI
COCKSPUR
CALIBOGUE SOUND
HILTON HEAD I.
Braddock Point
TYBEE LIGHT
WHISTLING BUOY
Notes
1852 Line shown thus
1884
1891
INDEX MAP
OF
SAVANNAH HARBOR GEORGIA
SHOWING PROGRESS OF IMPROVEMENT TO
JUNE 30, 1891.
SCALE OF MILES
From U.S. Engineer Chart.
L I N A
Bloody Point
NEW RIVER
TURTLE
WRIGHT'S RIVER
JONES ISLAND
OYSTER BED TRAINING WALL
LONG ISLAND
CHANNEL
COCKSPUR I.
COCKSPUR LIGHT
ISLAND
SAVANNAH AND TYBEE R. R.
LAZARETTO
TYBEE ISLAND
I
A


1879.
Atlantic Ocean.
St Johns River
Note.
6 ft contour
12
15
18
24
30
Sailing line.
Available mean low water on the Bar. 7.5
Middle Ground 16.0
1883.
Atlantic Ocean.
Soundings are exp.d in feet & tenths.
Av.ge mean low water on the Bar 6.8
M. Ground 16.0
1886.
Profile of North Jetty. June 1892
mean low water
Profile of South Jetty. June 1892.
Mean low water

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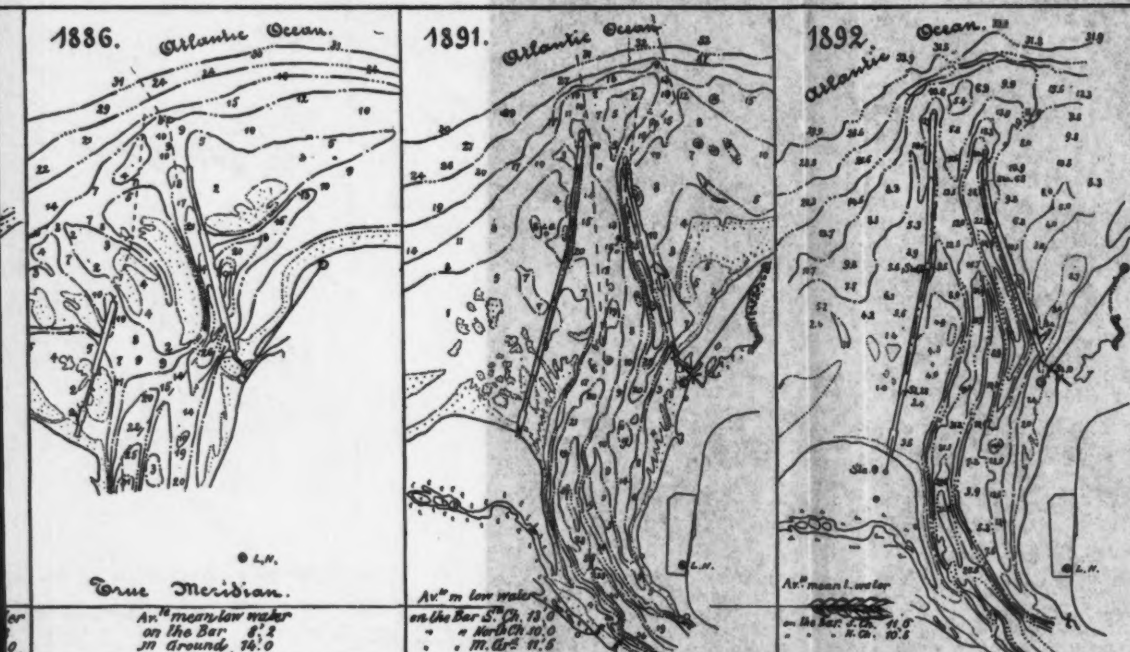
BLACK ON IMPROVEMENT OF HARBORS.
PLATE VII.



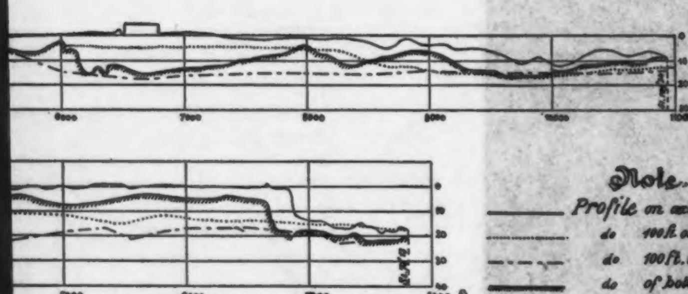
Improvement of St. Johns Bar, Florida.

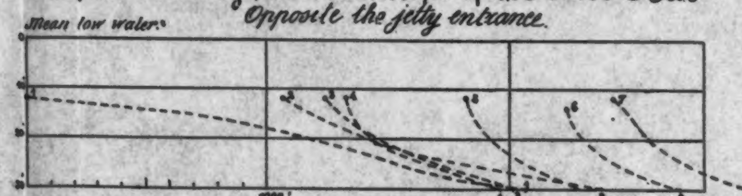
Comparative Charts showing the progress and effects of the improvement.

From U.S. Engineer Charts.

Scale

Profiles showing the mean slope of the outer Bar.
Opposite the jetty entrance.



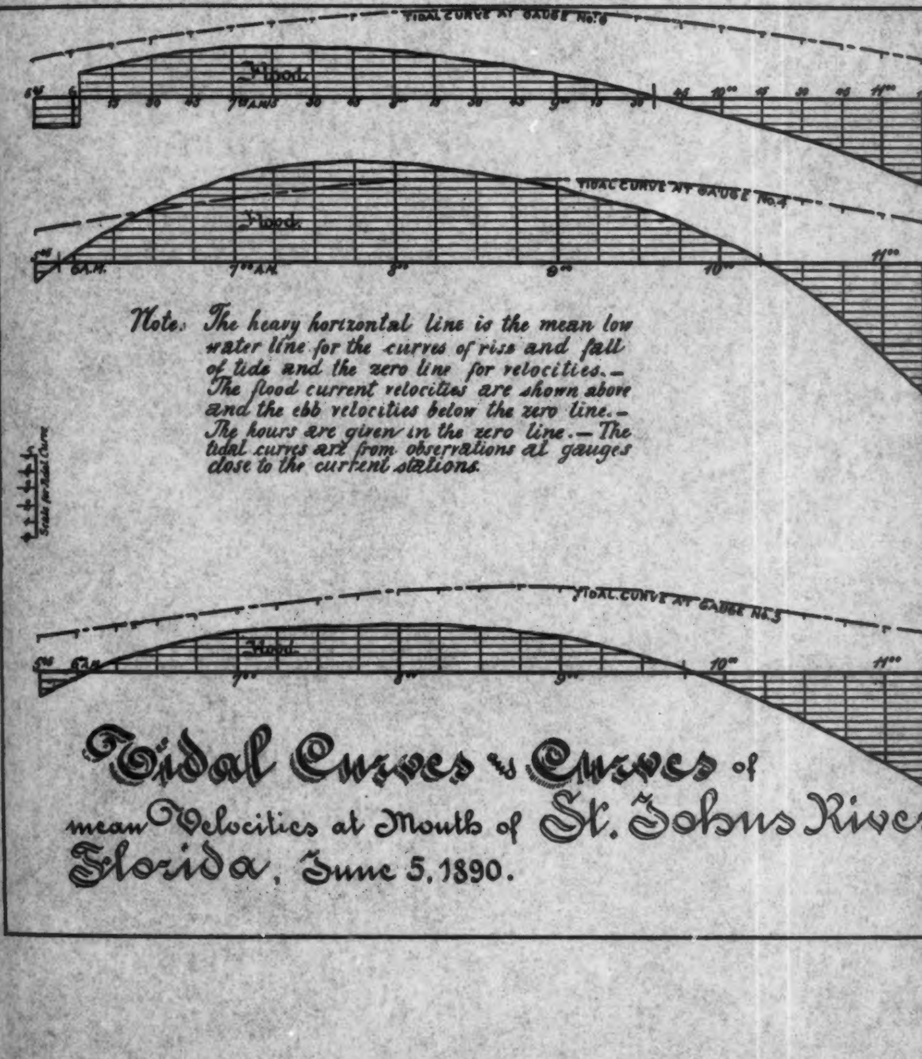


Note.

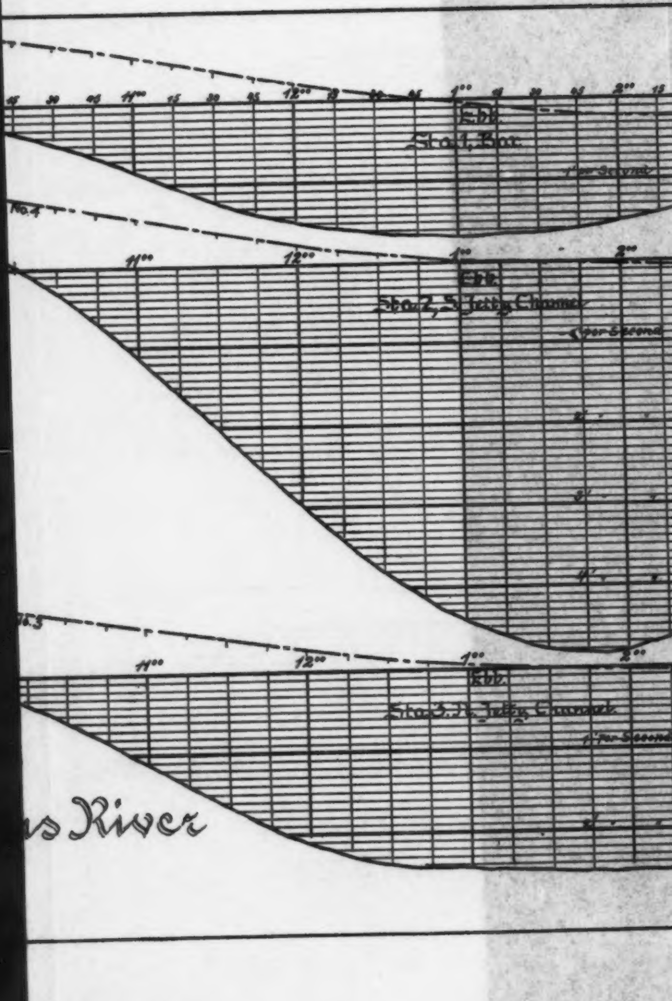
———	Profile on axis of jetty
....	do 100 ft. outs. of and par'l. to axis
-.-.-.-	do 100 ft. insd. of and par'l. to axis.
▬▬▬	do of bottom when mats were laid.

Curve No. 1 shows condition of June 1885
" " 2 " " " 1886
" " 3 " " " 1887
" " 4 " " Dec. 21st 1887
" " 5 " " Mar. 2nd 1888
" " 6 " " May 14th 1888
" " 7 " " June 1892

The Horizontal scale shows the actual advance Sea-ward.



Tidal Curves & Curves of mean Velocities at Mouth of St. Johns River Florida, June 5, 1890.



Ebb.
Sta.1, Bar.
1' per Second
No.4
11^00
12^00
1^00
2^00
Ebb.
Sta.2, S. Jetty Channel
1' per Second
No.5
11^00
12^00
1^00
2^00
Ebb.
Sta.3, N. Jetty Channel
1' per Second
s River

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TRANS. AM. SOC. CIV. ENGRS.
BLACK ON IMPROVEMENT OF HARBORS.
PLATE VIII.